AN INVESTIGATION OF THE AUTOMATION POTENTIAL IN SEVERAL GEORGIA INDUSTRIES

A THESIS

Presented to

the Faculty of the Graduate Division

Georgia Institute of Technology

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Industrial Engineering

By

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September 1955

AN INVESTIGATION OF THE AUTOMATION POTENTIAL

IN SEVERAL GEORGIA INDUSTRIES

Approved:

Date Approved by Chairman: 27 MARCH 1956

ACKNOWLEDGEMENTS

The writer is indebted to many persons who have contributed to this thesis. Appreciation is expressed to those members of the firms visited who have given their time and provided operating information for this study. The cooperation of the personnel of the Price Gilbert Library has been significantly helpful.

Doctors Mario J. Goglia and Rocker T. Staton, of the Mechanical Engineering and Industrial Engineering Departments respectively, have read this thesis and made valuable suggestions.

The most immediate and valuable influence was that of Doctor Robert N. Lehrer, of the Industrial Engineering Department, who acted as the thesis committee chairman. To Dr. Lehrer, who has guided this work with his characteristic perception, particular appreciation is expressed.

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CHAPTER I

INTRODUCTION, ORIENTATION, AND OBJECTIVES

BACKGROUND INFORMATION

In 1947, the manufacturing vice president of Ford Motor Company, Del S. Harder, used the word "automation" to describe the automatic handling of parts into and out of machines. Also in 1947, John Diebold presented his book Automation — The Advent of the Automatic Factory (1) in which he described the underlying factors and feasibility of automaticity in manufacturing and administrative operations[1].

Automaticity did not originate in 1947 with the coining of the word "automation"; the trend toward automaticity is of an evolutionary nature and has been in the minds of industrialists for some time. Degrees of automaticity had been realized in some applications such as ordnance manufacture, bottling operations, etc. without the benefit of this neologism, although these applications were somewhat widely interspersed. With the wartime scientific advances and a general post-war demand for economical volume production, the thought and realization of increased automaticity developed to a degree not previously considered.

The combination of these factors, in addition to demonstrations of compounded special machines for automatic manufacture especially by automotive production, and the short period in which the potentialities

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[1]Numbers in parenthesis refer to bibliographical references at the end of this thesis.

of automatic production were realized has developed into what is now known as the concept of automation. Automation has tempted the imagination of many persons, some of whom have predicted a "Second Industrial Revolution" in which a widespread conversion to automatic manufacture was projected as imminent. This has given labor organizations some cause for concern as to the future of their members. Thus far, automation has caused no major sociological disruptions; however the labor unions, notably the Congress of Industrial Organizations, have been investigating the developments with some diligence.

At present, the majority of applications have been in the automotive and other high-volume industries in which special machinery can be advantageously amortized. Installations in the medium-sized and lot-production firms have been almost nil, apparently because of lower capitalization, the need to retain flexibility, and the possible absence of technical ability.

DEFINITION

The need now arises of defining "automation". Its definition is, however, actually an academic point since, from the process designer's standpoint the name of the process is immaterial provided it accomplishes the desired purposes most efficiently. He will not design a method of manufacture on the basis of what it will be termed. Yet care must be maintained that potentially optimum methods are not overlooked because they are not included in an artificial classification of operations.

The use of the word "automation" is acceptable only if it does not restrict thinking. A broad definition is thus suggested. In its broadest sense, automation connotes automaticity. More acute refinements in definition become practically a matter of opinion; no technical body has presented a fixed definition (though the magazine Consulting Engineer (2) reports that automation is acceptable as a synonym for automatic control). The apparent purpose of the word is to differentiate the higher orders of control and automaticity from mechanization. The fine point of the definition would then be to define how automatic an automatic system must be before it is termed "automated". In opposition to a mechanistic definition, Mr. Harder has stated in a 1954 speech (3),

> "Automation, as you know, has become a phrase to describe everything that is automatic ...., Mr. E. W. Brainard of the Hughs Aircraft Co. defines automation as follows: 'Automation is more than a merely transferring. Nor is it a pushbutton factory. It is a philosophy that may extend back to the design of the product. It is a new method of manufacture, not necessarily a new way of cutting metal, but a way of controlling the various processes. Automation is a philosophy of design, it is a manufacturing method, and it is control within a machine'.
>
> "I like this particular definition because automation is labled a new manufacturing method. This I believe, is true. There are many other definitions equally as acceptable, but anyone who fails to recognize this fact has missed the point".

Diebold has declared that he contracted the word "automatization" to automation, based on his weakness of spelling the former.

Following these definitions, came a flood of others, a sample of which follows:

> Moross et al (4): "A concept which views the industrial process of an integrated system, functionally related, subject to internal and external disturbances which the system can be programmed to correct without the agency of human intervention".

C. E. Evanson; TAB Engineers, Chicago (5): "The application of machinery to perform and control automatically and continuously all of the manufacturing operations in a given plant — from the raw material to the finished product. It includes automatic transfer of material, automatic control and programming of operations, and automatic compilation and recording of data. Its objectives are: balanced production, uniform and controlled quality, and lower costs".

Richard Rimbach Associates (6): "Automation is the substitution of mechanical, hydraulic, pneumatic, electrical, and electronic devices for human organs of observation, decision, and effort".

The reader can now observe the range of definitions from the preceding sample. He is furthermore entitled to his own definition on the basis of his experience and interpretations. However, in a previous investigation of the meaning of <u>industrial</u> automation, using the connations of the published literature and guidance of the previous definitions, the following definition of industrial automation has been formulated by the writer...

Industrial automation is that process or operation in which the equipment involved is self-regulated with ancillary control equipment which simulates human sensory functions and causes those physical actions necessary to the execution of the process to occur.

Mechanization is traditionally defined as the substitution of machinery or mechanical power for human or animal power; automation is then differentiated from mechanization in that automation implies automatic <u>control</u> of machinery with other machinery.

NATURE OF THE PROBLEM AND THESIS OBJECTIVES

In many of the publications in which automation is treated, there appears little information of a broad organizational scope and of an analytical nature. Much of what is presented is philosophical, illustrations of specific units and applications, prognostications, opinions in concurrence that automation is beneficial and is often directed to management. In some of the more technical journals, there is concrete and definite information concerning the industrial process. These, however, are of a specialized nature and are not presented as a facet of a more general scheme of organization. Furthermore, there has apparently been no attempt to examine the potentialities of a group of manufacturing organizations to utilize the developments in automaticity, and to develop general principles of application, if such exist. These deficiencies are the basic problems which this thesis attacks.

The specific objectives of this effort are:

1. To survey current publications relating to automation in order to assemble technical information concerning the basic elements involved in automation for industrial applications.

2. To propose principles of automation that may be used as guides for evaluating possible automation in industrial situations.

3. To investigate the basic processes involved in several Georgia industrial plants, and to attempt to apply the proposed principles of automation to the processes to evaluate the automation potentials of these activities.

4. To evaluate the general applicability of the automation concept in the selected Georgia industries.

Grey Walter (7) has written, "... where there is pattern there is significance". If automation is to be accepted as a significant concept in manufacture, the converse should apply. Consequently, in addition to and underlying the other objectives of this thesis, there is a search for pattern.

PROPOSED GENERAL DIVISIONS OF AUTOMATION

From a survey of the literature concerning automation, there are several general areas in which improvements have been made to facilitate the automation of a process. These divisions, presented below, are proposed as a basic organization of automation and are here used as the major thesis organization.

The divisions in which a process becomes automated for a given product is one or more of the following:

1. In the physical performance of an operation on a product. This encompasses changes in machinery and method.

2. In the movement and feeding of the product between operations and into and out of machines. This is traditionally regarded as materials handling, but here is added automaticity in the form of specially built moving mechanisms to move the correct quantity of material at the correct time and in the correct position, without human handling or direct human control.

3. In the use of information processing devices to store, determine and produce controlling information for the operation to effect the necessary operating changes. While usually known as automatic control equipment, such units are viewed as basically information processing devices.

In addition to these process considerations, there are possible product changes which would allow favorable reconsideration of the three above actions for possible automatic production[2].

The next four chapters of this effort are concerned with the developments in these areas over the traditional methods of performing them. The section on materials and methods is presented first, followed by a chapter on automatic materials handling. The last two chapters are concerned with automatic control and are entitled "Methods of Automatic Control" and "The Use of Computers for Process Control" respectively. The chapter on computers has been separated from the general treatment of automatic control since control with general-purpose computers is somewhat unique and its potential practicality has not been demonstrated in an actual process control installation.

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[2]Printed circuits are an illustration of such a favorable product alteration.

CHAPTER II

CONSIDERATIONS OF EQUIPMENT AND METHOD

In order to perform value enhancing actions on a workpiece, it is usually necessary in the modern industrial process to use certain units of machinery. The physical nature of such equipment may vary between standard units and special purpose units, recognizing that any specific unit may exist on a continuum between these two classifications. Automation has been advanced through the use of special equipment and modified standard machinery, and many organizations offer their services for the construction of such machines; among the larger of them are the Cross Company, the Kearny and Trecker Corporation, and the W. F. and John Barnes Company.

Theoretically, a machine can be constructed to accomplish any given function, though for many operations the construction of a special, completely automatic machine will be complex to a degree which renders it economically infeasible. Consequently, the feasibility of constructing a special machine is governed by the potential economic advantage; it has been found warranted in many operations, infeasible in others, with many yet remaining to be considered.

The use of special machinery to accomplish an operation in its existing form is then a frontal attack on the problem of feasible automaticity. In the case of sewing a button to a garment, undoubtedly a machine could be designed which would automatically position the garment to the sewing instrument, position the button to the garment, and automatically perform the intricate loops necessary to attach the button. Visualizing the normal button with two or more holes, the unit required to accomplish this sewing operation may well pass the point of economic feasibility and remain as a possible solution, but not a practical one.

The construction of a special machine to perform an operation in its existing form is one solution to the problem of basic considerations for automation of a process. It is logical to ask, what are the remaining alternatives? As one executive said, during a visit in connection with this thesis, "Anything can be made automatic if you are willing to spend enough money to do it". The author proposes that many operations can be made automatic within the requirement of economic feasibility if one is able to devote the time and effort necessary to comprehensively consider the operations. These considerations along with Diebold's remarks on "rethinking" infer that there are additional factors inherent in the creation of an automated process. These, it is believed, are the processing method, and the functional consideration of the product. Manufacturing method and product are, of course, interrelated; changes in one usually affect the other. However, a physical change in the product may not affect its functional characteristics though it may allow an advantageous change in the method. Conversely, a functional change in the manufacturing method may cause a physical change in the product yet preserving its functional utility. In the previous example of button-sewing, these considerations indicate that the functional characteristics of the button should be analyzed. What is its purpose? The purpose of a button is to close an opening in a garment. This functional consideration of the product should then lead to considerations of other lative motion between materials and operating instruments instead of the traditional materials handling methods.

Regarding the product, physical appearance is often a consideration which retards physical alteration even though the functional characteristics would be undisturbed. The previously mentioned button, for example, actually has two desirable characteristics. One is the function of closure and the other is aesthetic value. When the button is used for the aesthetic value alone, physical change is undesirable; but when its value is purely because of the closure characteristics, then there is a possibility of alteration or substitution of another item which also accomplishes the function, but which allows advantageous process changes. Aesthetic properties are an element of some products for which there is a specific demand. Many products are sold because there is a customer demand for that particular item, and a physical product alteration may ruin the market. Consider, for instance, the publishing of a book; this involves typesetting, printing, and binding. Functionally, the object is to convey information from one source to another and there are many other media by which this communication can be accomplished; but a book is of such a nature that there is a demand for information in this particular form.

Consequently, the product requires careful analysis of functional characteristics; to overlook such functional product considerations is an omission of a potential advantage.

The evaluation of a manufacturing objective both from the standpoint of the product and the process is a fundamental consideration and is therefore a pattern-like attribute. Functional evaluation is a definite aide to ingenuity at its least value.

methods of closing the opening, and consequently methods of fabricating the items suggested by a functional analysis.

An overall functional view of the manufacturing procedure often can lead to physical, but not functional, alteration of the product. The question to be answered here is, "What functions must be performed to achieve the finished product?" (With the desired characteristics of the finished product stated in broad functional terms). These functions are not drilling and machining, but material removal; not packaging, but protecting and unitizing; not riveting, but securing, fastening, or joining. It is proposed then, that there exist other methods of accomplishing the desired operations that are more adaptable to automatic manufacture; what is apparently required is non-restricted thinking in broad functional terms. The project "Tinkertoy" development is interesting in this respect. The function of fabrication of electronic units is to unite components in different combinations (rather than soldering connections). This has been accomplished by mounting the components on standard size "wafers" which can be automatically stacked in various orientations and combinations. Electrical connections are accomplished by the standardized attachment of straight wires to the exposed terminals on the edge of the automatically oriented wafers; the wires also serve as the supporting member for the assembly. Thus the need for intricate manual wiring has been eliminated and also the need for the traditional metal chassis as a base.

Such functional evaluation appears to be of advantage for individual operations also. This approach may have been a consideration in the design of those machines using rotary indexing tables to achieve re-

CHAPTER III

THE MATERIALS HANDLING FUNCTION IN AUTOMATION

Materials handling, being a subject of broad scope, has been divided into internal and external materials handling, where internal handling is within the confines of a plant, and external handling is that which is concerned with longer distance handling by rail, ship, trucking, etc.. Internal materials handling has been further subdivided into handling prior to manufacturing operations, handling during the process, and handling after the final operation, but before external shipment. These operations have been termed "transit", "process", and "distribution" handling respectively.

The object of materials handling is to move material from one location to another with the minimum expenditure of money. This objective then sets a theoretically correct method; that which will provide maximum profits[1].

With the developments in controls, and the concept of increased automaticity, have come developments in materials handling which can often provide a savings over traditional methods. This chapter is concerned with the developments and possibilities in each of the three internal handling areas, separate discussions of which follow:

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[1]Safety is also a consideration, but it is intended that this be included in the profit function.

TRANSIT HANDLING

Transit handling is characterized by the unloading of raw materials from an external carrier, storage, and introduction to the process. Materials are either in the form of discrete products, which is usually the case in fabricating operations, or continuous flow products, such as oil. The flow products present little handling problems, while the discrete units are more troublesome, requiring individual unit handling.

Regarding discrete products, unloading, storing, and introduction of materials to the process presents some intricate variables which have made automatic handling in this phase difficult. First, the location of the unloading operation may vary; second, the material may be in many different forms or enclosures; third, the location of the storage area is usually a constantly changing variable; and fourth, the point of introduction to the process may vary. Consequently, flow routes and product nature are major considerations. Man-mechanical handling equipment combinations have provided in most current cases, the optimum solution to these problems.

However, advances have been made in the form of specially built machines for breaking incoming unit loads. Carton and case unloaders for the bottling and canning industries have been devised. The Food Machinery and Chemical Corporation offers pallet unloaders (and loaders). In many cases, where fixed routes can be maintained, elaborate conveyors with diverters and automatic switching sections have been used.

Using the flow processes as an ideal system of automatic handling, observations thereof indicate that all possible flow routes are installed, and the route for any given lot of material is selected and accomplished by opening and closing channels. Such is also the case in a rail yard, which however, deals with discrete units. This concept for flexible handling has been partially transferred to industrial handling in the form of overhead "tracks" between which four wheel trucks are automatically switched. The Barret-Cravens Company accomplishes this same function electronically; the "tracks" are in the form of antenna which are strung over the various possible flow paths, and through push button energization of a flow pattern, a tractor trailor train will proceed according to the selected pattern. Provision is also made for automatic load detachment. Such methods for providing automatic multiple flow paths to achieve flexibility in the fabricating industries, as exist in the flow processes, bear attention when considering specific applications.

The remaining problem of loading and unloading is one of more complexity, depending of course, on the particular product or products. If a "welding" of static storage containers and the moving medium could be accomplished, this function of transfer between media would be facilitated or eliminated. Actually the pallet-fork truck system approaches this concept; the moving medium (fork truck) moves both the static container (pallet) and the product. This weld could be accomplished (and has been in some limited applications) by live conveyor storage, or the use of four wheel containers as both the dynamic vehicle and static storage container, as is done in many laundries.

To summarize, two concepts of potential value have been discussed: one, the use of flexible, automatic, multiple flow routes; and two, the welding of static storage containers and dynamic moving vehicles.

DISTRIBUTION HANDLING

Distribution handling is the converse of transit handling with the materials in a processed and altered form. The sequential procedure in this phase is packaging and/or unitization, storage, and loading to an external carrier.

Automatic packaging is a realized accomplishment in many high volume processes. It usually entails the use of special or semi-special machines to unitize products in containers. Automatic carton staplers and sealers are now sold in standard models. For unitization of larger units, the Food Machinery Corporation, and other firms, have made automatic palletizers available. The canning and bottling industries have capitalized on these automatic packaging and unitizing developments.

The problem of handling between unitizing and storage, and between storage and shipping locations is identical to that considered under transit handling; the concepts developed there are also applicable after the packaging function.

PROCESS HANDLING

Fabricating operations assume the characteristics of continuous and job-lot manufacture in varying degrees of emphasis. Observations of the developments in materials handling for continuous production, and considerations for accomplishing materials handling automaticity for job-lot manufacture are discussed separately below.

MATERIALS HANDLING IN CONTINUOUS PRODUCTION PROCESSES. Automatic materials handling in those processes with continuous run characteristics have been observed to use two types of handling, and combinations of these types. Materials are either transferred between machines, and automatically fed and unloaded, with special equipment; or machines are closely grouped around a central materials handling unit. In this latter case, the materials are operated upon while on the materials handling unit and in effect, do not require individual machine loading and unloading. Transfer machines and indexing rotary table machines are examples of this grouping.

For intermachine transfer, conveyors such as is shown in Fig. 1 are used; these conveyors are usually designed to accommodate a specific product. Methods of loading and unloading vary widely with the nature of the product and machinery. Fig. 2 illustrates one type of feeder known as a rotary barrel feeder which orients parts and continuously feeds them to the operation through a product-designed channel conveyor. The lower illustration of Fig. 2 shows such a feeder supplying a chamfering machine.

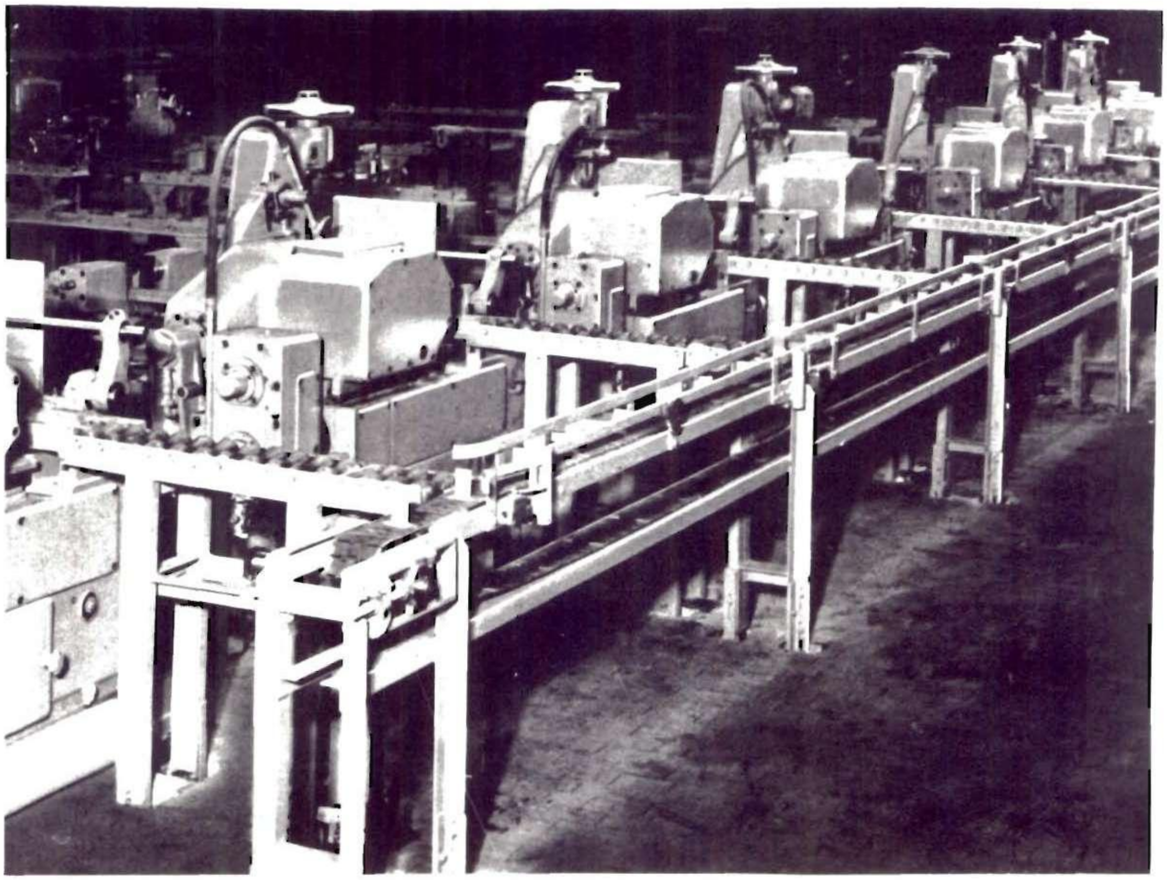


Fig. 1 A product-designed conveyor which receives ordnance billets from a bank of cut-off machines and delivers them to the next operation. (Photograph courtesy W. F. & John Barnes Company)

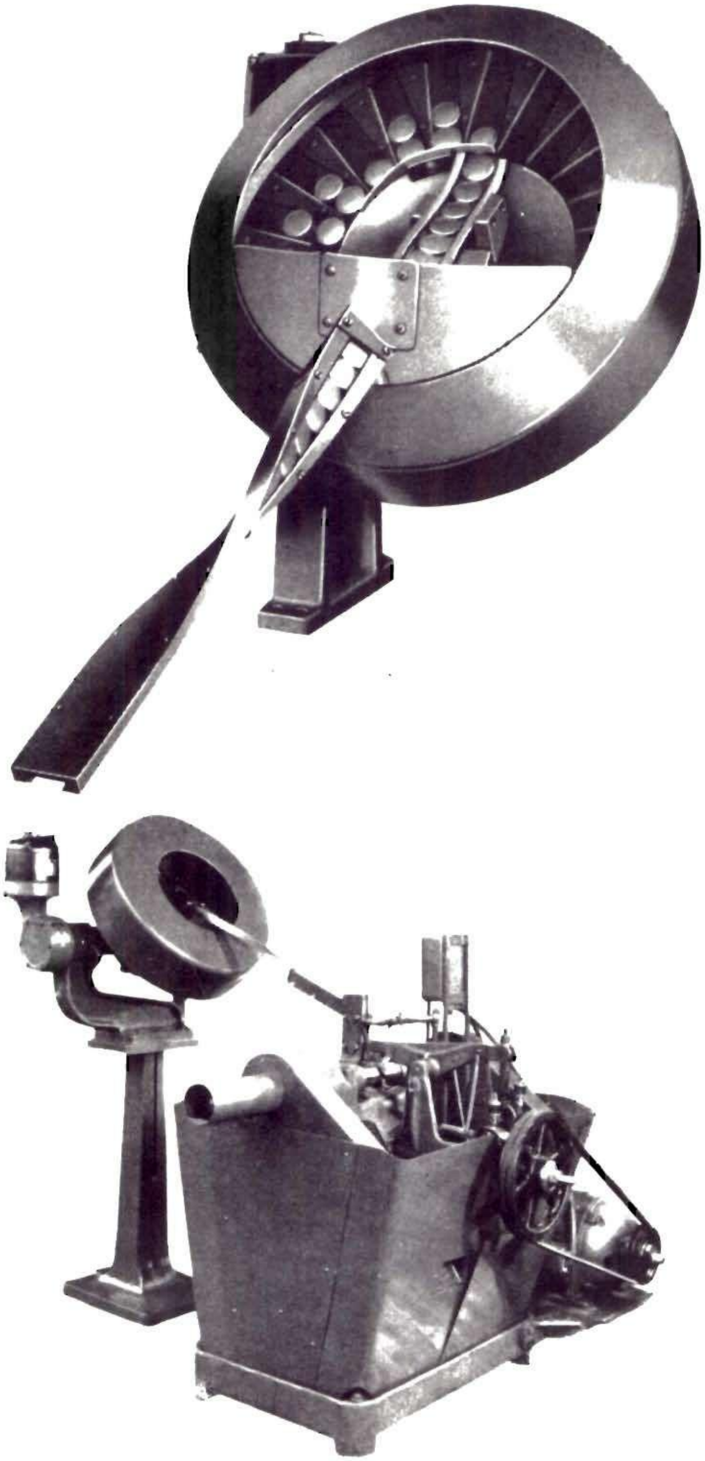


Fig. 2 Illustration of a bowl feeder. Upper photograph shows details of a feeder, and lower picture demonstrates the feeder supplying a chamfering machine. (Photograph courtesy of Detroit Power Screwdriver Co.)

MATERIALS HANDLING IN JOB-LOT PRODUCTION PROCESSES. An extreme case in lot production is one in which each product is different from the preceding one and is not routed to any of the machines used by the previously manufactured product. Most job-lot processes do not approach this extreme and often produce only variations of several basic models. As the number of these basic models decrease, it is increasingly possible to segregate like operations and perform them in a continuous manner.

If flow routes are well defined and are relatively stable for the different runs, the possibility exists of installing automatic inter-machine handling equipment and automatic feeding and unloading units with a provision for changing <u>critical</u> routes between runs.

Another possibility for increased automaticity is the use of universal feeding equipment for the special purpose machines sometimes used in lot production. These machines often receive parts with a common attribute; such a machine is the centerless grinder. The parts processed will always be cylindrical and it is conceivable that a feeding device for this type of machine can be designed which will accomodate all products.

The method of handling in which parts are placed on a central materials handling unit with close machine grouping can sometimes be used in the lot process, though not always in a completely automatic installation. Fig. 3 illustrates semi-permanent tooling around a dial feed installation which can be rearranged as the lot characteristics warrant.

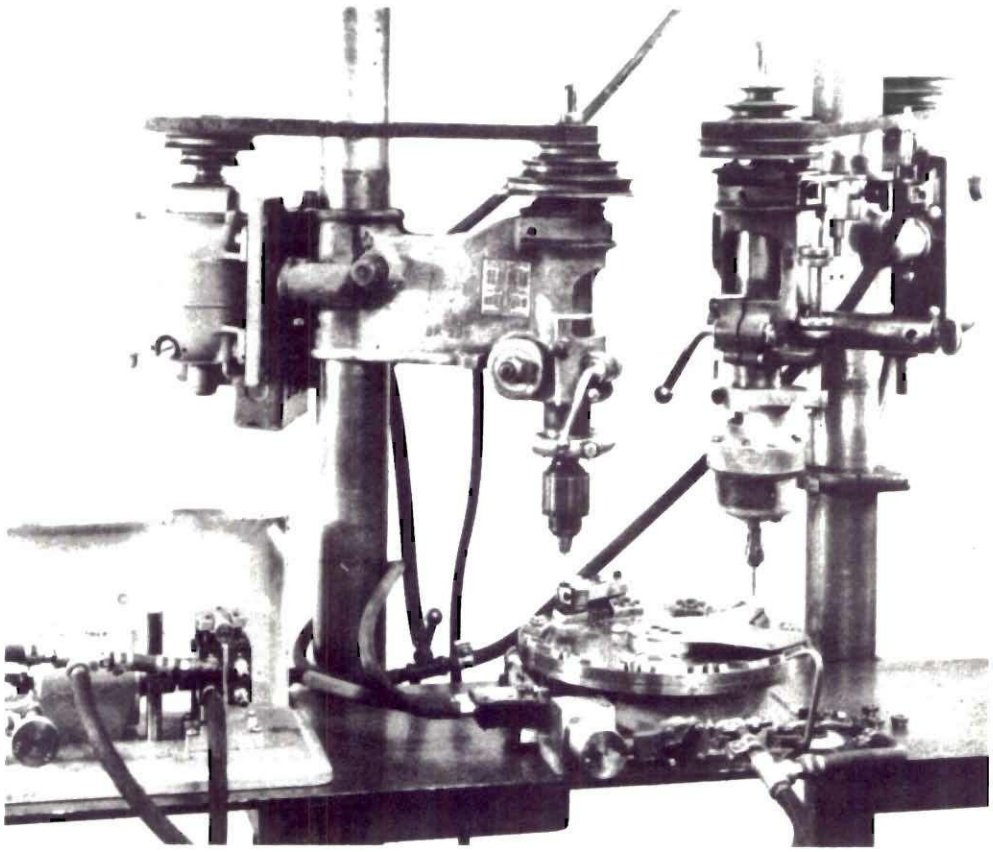


Fig. 3 A semi-permanent dial feed installation with two operations. (Photograph courtesy Mead Specialties Company)

An observation of the flow processes indicates that materials are easier to handle in continuous form than in discrete form. In some processes, materials are received in continuous form, such as paper rolls, only to be transformed into discrete units. It may be possible to retain the material in the continuous form longer than is currently done, thus allowing for continuous and less troublesome materials handling. This, of course, mandates that some operations common to all product variations can be performed on the products in this state.

Consequently, it is observed that lot production requires flexible materials handling; however, some of the characteristics of volume manufacture exist in most lot processes. It is suggested that these operations be segregated and performed with the techniques of continuous manufacture and materials handling.

CHAPTER IV

METHODS OF AUTOMATIC CONTROL

Before discussing the physical methods of automatic control, it is interesting to trace the industrial operator functions in terms of their association with various machine complexes. The functions are considered important since they are those that are assumed by the mechanical units of control equipment.

The most basic operator function is that of pure hand operations with no mechanical equipment. The operator both controls the operation and furnishes the power to accomplish it. A large section of this category is that of hand assembly which, because of the intricate positioning of components necessary, would require a unit of some complexity to accomplish these functions.

Basic hand tools such as hand drills, files, and hammers are the next combination. The operator also performs all of the control functions, though he now possesses a mechanical advantage to assist him in his work, though his muscle power is still the primary source of energy for accomplishing the operation.

One level above hand tools is the powered machine with which the operator may accomplish useful work with the assistance of external sources of power. He still performs all necessary control functions and on occasions uses muscle power to assist the machine such as is done on a wood lathe. This is the beginning of the mechanization "area" in which power other than that of the operator is introduced to the operation.

Controls are first introduced to the operation in semi-automatic operations. Operator functions are primarily those of control with the minor automatic controls assisting him. Energy is required of the operator only in making the necessary control adjustments. An example of such a semi-automatic machine is the standard machine lathe with its automatic speeds and feeds. The operator must obtain information regarding the correct value of these variables and make the appropriate settings on the machine controls. In the semi-automatic machine, as in the non-automatic machine discussed above, the operator also handles workpieces into and out of the machinery.

Using an automatic machine, such as a turret lathe, or an automatically cycling unit, the operator is primarily concerned with loading and unloading materials from the machine and actuating it at the correct time. Most control functions are performed by physical equipment and often the operator needs little or no skill, the set-up or maintenance functions being performed by indirect labor. Many of the current industrial operations exists in this state today and are on the "brink" of automation. Operators perform the functions of loading and unloading and actuation of the machine at the correct time (if such actuation is required at all).

The automatic machine which requires an operator for loading, unloading, and limited control action is the terminal point of the mechanization "area". Just inside the automation "area" is the fully automatic machine which receives parts from an external source, automatically loads itself, performs the required operations, unloads itself, and prepares for the next operation. Only indirect labor is required in this operation; material is either automatically positioned from bulk storage, or is fed continuously from a previous operation. Semi-continuous feeding, such as that of bar stock to an automatic screw machine is also possible.

It is also well to note that these fully automatic machines evolve into two classifications: those which are used for continuous production of an unvarying product, and those which are used in lot operations. In the former, the repetitive control operations may be built into the machine and are of a relatively permanent nature, while in the latter, there must be a provision for altering control information. The equipment which accepts varying control information and consequently automatically performs varying physical actions on the basis of this information is here termed "flexible automatic machine systems".

The range of operator control functions to the point where the machine control system exercises complete control has been traversed. However, there is still a possibility for human control when two or more fully automatic operations are compounded into an automatic unit or system. As the system complexity increases, the possibility of the occurrence of an event outside of the design characteristics of the automatic system increases. To provide for automatic responses to these occurrences, it is often necessary to infeasibly compound the control system. The major advantage of human control is that of flexibility; therefore at some point in the control complex, it becomes feasible to use a combination of human and automatic control. The human mind has some drawbacks also. It can remember large quantities of information and correlate such information into logical decisions, but when required to translate this information into intelligent responses at high speed, it can easily become confused and make errors. Other characteristics which limit the feasibility of human control are:

1. Variations and limitations of human response
2. Development of fatigue, tension, and monotony
3. Inconsistencies in human reactions
4. Inaccuracies and varying sense of judgement
5. Limitations of temperature, pressure, vibration, etc., that the human body can stand

Sperry (8) states,

> "The ideal combination of man and machine will be the one in which the man will use his brain to analyze, form judgements, and initiate commands, while the machine takes over all of the information gathering and repetitive control operations where its inherent capabilities of speed and power are most effective".

In an automatically controlled system, control information is presented to the controlling mechanism in a form which requires no intermediate human interpretation for actuation of machinery. Through the use of automatic controllers, operators then assume the function of controlling the controllers; this action is here termed "second-order" control.

Consequently, past a point of complexity, the human mind remains as the only feasible information processing device. The use of digital and analog computers for overall process control, as is projected, will possibly push this frontier of feasible automatic control even further.

ORGANIZATION

Control mechanisms appear to evolve into two classifications: those which are concerned with continuous variables, and those concerned with attribute variables. Also, manufacturing processes are similarly divided; there are those of a continuous nature such as the petroleum processes, and those of a fabricating nature in which each operation is discrete. This division is amplified by Ayres (9) statement,

> "A refinery is a model case of the kind of manufacturing operation known as the continuous process, in contrast to the discontinuous step-by-step operation of the automobile assembly line".

Certain specific processes appear to have combinations of both types of manufacture.

A distinction of terminology is desirable; the term "operations" shall refer to fabricating operations while "flow processes" shall refer to those continuous processes characterized by petroleum refineries. The term "process" without modification is considered to be a general term denoting either or both types of manufacture.

Considerations of closed loop control which is of general interest in automatic control is discussed next. Following this treatment are separate discussions of flow process and fabricating operation control based on the previously discussed division.

CLOSED LOOP CONTROL

Of basic importance in automatic control and common to both flow and fabrication processes, is "closed loop" or "feedback" control. It is a means by which variables are maintained at a desired value, without human intervention, and the basis for self-correction and self-regulation. Functionally, reference control information is placed into the feedback system which is "consulted" and compared with observations of an actual process value. If there is a difference between the desired and actual states, the control system then takes appropriate corrective action. The functional relationships of the elements of the feedback loop are shown in Fig. 4. The desired value of the controlled variable known as the "set-point" is introduced to the system in a unit called the "Reference Input Element". This control information is, in effect, stored here for future use. Omitting the next two units temporarily and proceeding to the unit labeled "Process", which for simplicity can be considered a process with one controlled variable, it will be observed that a disturbance of various origins can cause the process variable to deviate from the desired value. The output, or the magnitude of the controlled variable is detected by the unit titled "Feedback Element" which <u>may</u> transduce the measurement into another physical system (such as changing a measurement of revolutions per second to a voltage). This indication of the output is "fed back" to the "Controller" which compares the actual variable value to that which is stored in the "Reference Input Element". If these values do <u>not</u> coincide, the deviation or error is noted by the Controller which generates an "error signal" as a function of the variation. This error signal is fed to the "Final Control Element" which makes a physical correction which will return the variables to the desired value. The deviation of a variable initiates action to correct itself, and hence the reason for the term "closed loop".

This closed loop need not be in the form of a mechanical, hydraulic,

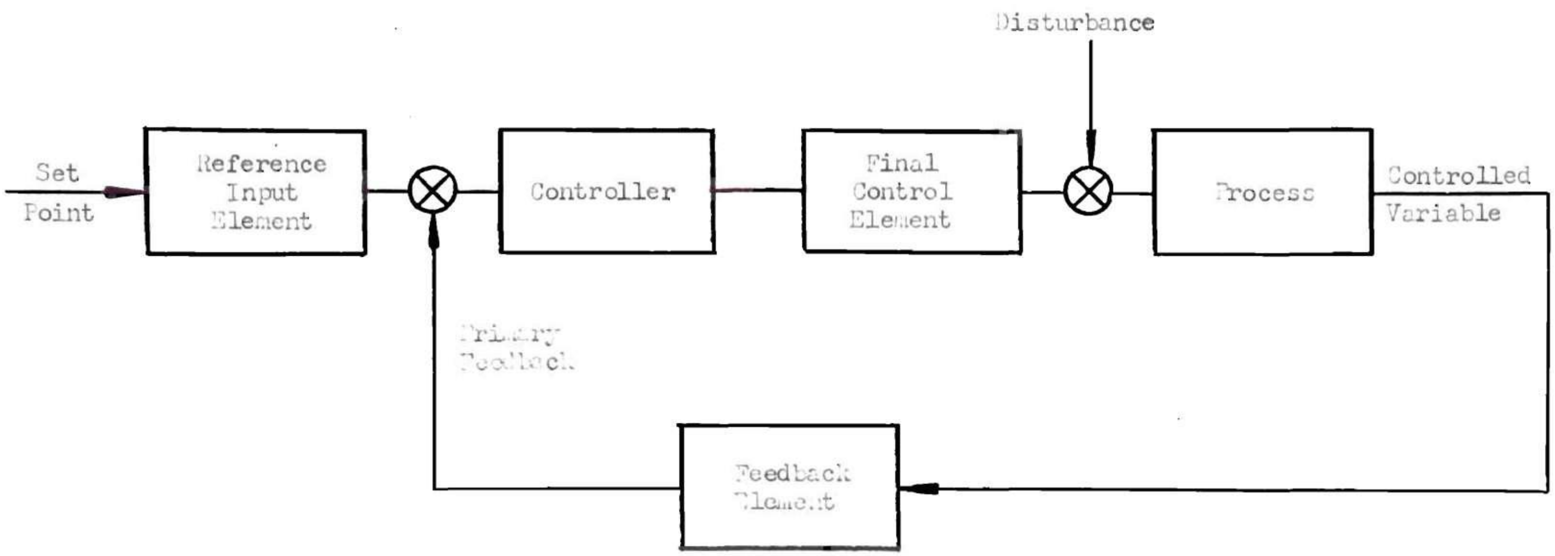


Fig. 4 Functional Diagram of Basic Feedback Loop

or electronic system; it could be and often is, closed with a human element. An operator could be instructed to maintain a desired value and to make correcting adjustments manually on the basis of the difference in the actual and desired values. The most simple solution to a control problem is to assign an operator to the job, thus obviating the need for automatic equipment. Nevertheless, the modern oil refinery would not function with its present efficiency with such individual control of each variable. It is suggested that there are opportunities to advantageously utilize feedback control which have not been previously observed.

It would not be objective to overlook those automated systems which do not utilize the feedback loop in their control functions. It should be noted that feedback is not, and need not, be utilized for control when the variable deviation is slight and/or is not critical. In addition, feedback is not used in some applications of machine control and sequencing since this is primarily an on-off regulation and an error here is usually one of such complexity as to require human correction. If a deviation occurs in an "on" control, it is a 100 per cent error since the only other possible state is the opposite.

In summation, the underlying method of self-regulation through a closed control loop has been outlined, with the suggestion that there are opportunities for applications not heretofore considered.

AUTOMATIC FLOW PROCESS CONTROL

In accordance with the previously presented difference between the flow and fabrication processes, and the consequent difference in their characteristic variables, this section discusses briefly the general types of controllers used for continuous variables. The feedback phenomenon is particularly applicable to control of continuous variables and is used in all of the classifications to be presented.

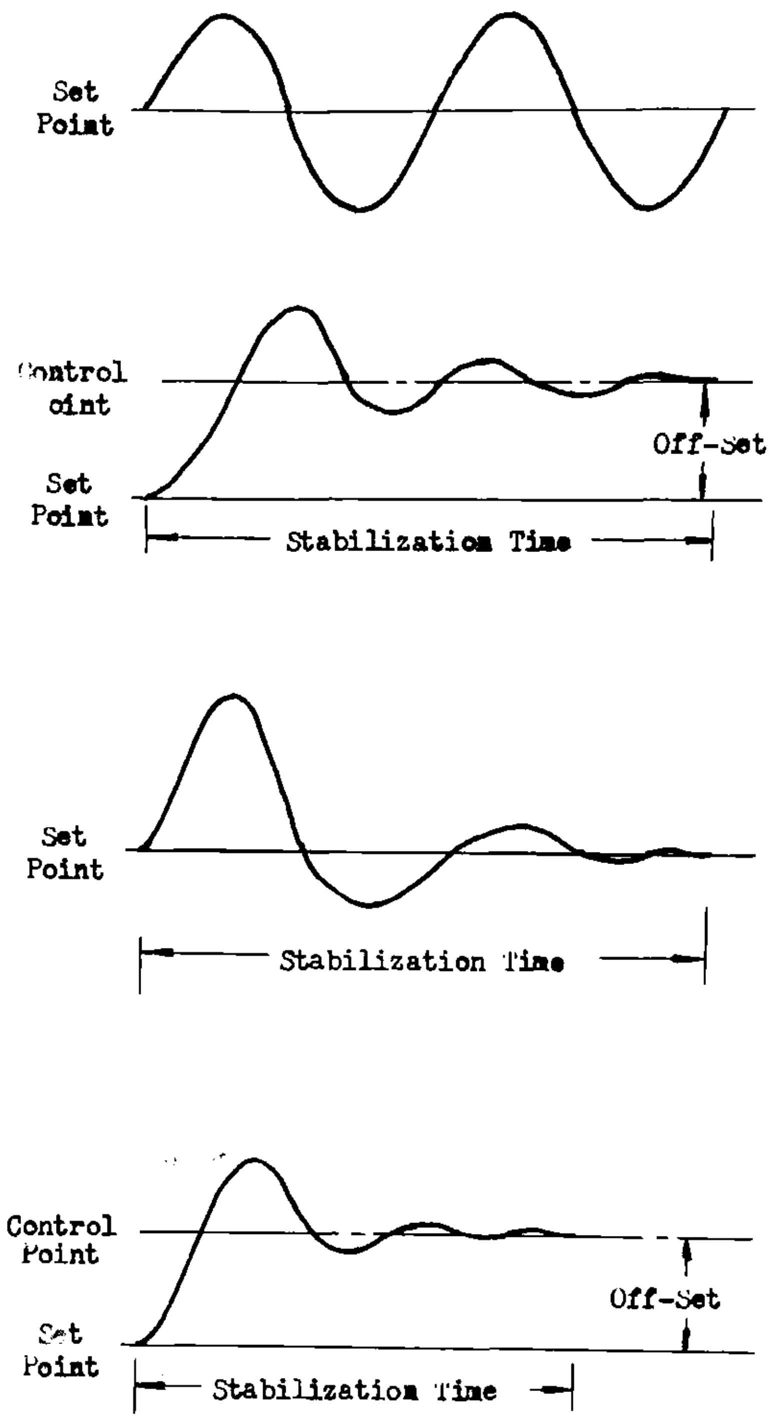
The corrective action obtained from a controller as a result of a variable deviation is known as the controller "response" or "mode" of control. Process control theory is comprised of the difference in the various major controller responses, which are:

1. Off-on or two position response
2. Proportional response
3. Proportional plus reset response (or "floating mode of control)
4. Proportional plus rate response

Each of these responses causes different variable fluctuations and has other characteristics which makes the use of one mode more advantageous than another for a given application. Brief discussions of each of the four modes follow.

OFF-ON OR TWO POSITION CONTROL. Two position control is that control response in which the final control element (such as a valve positioner) can only be positioned in one of two positions, usually either a maximum or minimum value (off or on). When controlling a variable about a given value (the control point), it causes continuous fluctuations as shown in Fig. 5. This action is known as "hunting" in control terminology.

Though two position response is the least acute of the four modes, it is satisfactory in many installations where a variable must be controlled within a relatively broad range. Such is the case in a thermostat for a home



ON-OFF RESPONSE

Characterized by hunting action.

PROPORTIONAL RESPONSE

Eliminates hunting action. Introduces off-set except for constant input flow rates.

RESET RESPONSE

Eliminates hunting action and off-set.

RATE RESPONSE

Eliminates hunting action. Reduces stabilization time. Introduces off-set except for constant input flow rates.

Fig. 5 Typical variable fluctuations under the four modes of process control. Vertical scale is deviation from desired value (set point). Initial deviations caused by process disturbance .

heating system; fluctuations within the range of 2-3° F. are not critical. This is illustrative of industrial variables which require control but not acutely so.

PROPORTIONAL RESPONSE. Proportional response is that controller action in which adjustments of the final control element are in a continuous linear relationship to the value of the controlled variable, or that action in which a valve would be opened in proportion to the deviation from the desired level. Correction of the variable deviation is therefore in proportion to the amount of the deviation.

Fig. 5 also illustrates the characteristic variable fluctuations for this mode of control. It gradually dampens a fluctuation to an insignificant amount. Proportional response has one major failing, however; when an input flow rate to the controlled process varies, the proportional controller will not return the variable to the desired value which has been set into the controller (the set point), but will dampen the variable at some value removed for the set point (off-set) as illustrated in Fig. 5.

Proportional response is desirable in those cases where variable changes are frequent and the fluctuations of off-on response is undesirable. In addition, it is necessary that there be no significant input variations.

PROPORTIONAL PLUS RESET RESPONSE. The problem of off-set in proportional controllers is eliminated with reset response by an added provision in the controller mechanism which compensates for input flow changes and thus eliminates off-set.

PROPORTIONAL PLUS RATE RESPONSE. Proportional response, as has been stated, corrects a variable deviation in a linear proportion to the magnitude of the variation. However, in some instances, it is desirable to return the variable to the desired value more rapidly, and this is performed by controlling the final control element in proportion to the rate of the deviation. Consequently, as is shown in Fig. 5, the variable is dampened in less time than with any of the other modes of control, but the problem of off-set is again introduced. To eliminate the off-set it is necessary to introduce a reset mechanism into the rate controller which is known as a proportional-plus-reset-plus-rate controller.

It is worthy of note that there exists a controller which actuates the final control element in proportion to the acceleration of the variable deviation, known as "second derivative response".

DISCUSSION. Regarding the mechanics of the controllers, they are usually pneumatic or electrical in nature. In some cases they are hydraulic. However, the use of electronic means for error-detection and signal amplification is increasing.

Electrical controllers detect and amplify errors through the use of a bridge circuit such as the well-known Wheatstone bridge; pneumatic controllers detect and modify the error signal by various combinations of bellows, nozzles, and flappers which act on low pressure sources of air. These controllers are essentially simple, special-purpose analog devices. They convert the measurement of the primary sensing element into an error signal, most usually a mechanical displacement, change it to an easily handled pneumatic or electrical variable, operate on the variable and transmit it to a power unit which completes the feedback loop and controls the process through a valve or other device. When controls such as have been illustrated are used to correct mechanical position instead of variables such as pressure and temperature, they are called position servomechanisms. Such servomechanisms have been used in fabricating operations to control contour and numerically-controlled machine elements.

The use of these controllers in the flow processes had obviated the need for individual manual control of each variable and has enabled the process to operate at a speed at which manual control would be impractical. The basic reason for this, of course, is the construction of devices which can interpret control "instructions", obtain operating information from the process, and actuate a correcting unit on the basis of a comparison of the desired and actual values. When, for instance, pressure is transduced to a voltage, the <u>desired</u> pressure value must be presented to the reference input element in a corresponding voltage. This voltage (without visual indicators) would mean nothing to a manual controller as written instructions would mean nothing to the mechanical control system. Hence, when investigating a process for possible automation, it may be advantageous to determine the present means for storing and utilizing control information, and possible other means which would facilitate the use of an automatic control system.

CONTROL OF FABRICATING OPERATIONS

The characteristic variables of the fabricating process are the off-on, yes-no, two-state variables of the step-by-step operation, and consequently the controls for these operations are limit switches, relays and the like which are also of a discrete nature.

Postingl (10) usefully differentiates between power and pilot controls; accordingly, he has stated, as an example, that power circuits connect an electric source to motors, whereas pilot circuits connect control accessories such as relays, timers, etc. in combinations to control the power connections. This section is concerned with these pilot and not power circuits. "Pilot circuits" as used by Postingl serve to indicate those devices shown in Table 1 (in which some flow process control transducers have been included), however, the term pilot circuits is extended here to include all devices of higher order control.

Among the devices used for control of discrete events are: limit switches, mercury switches, stepping switches, pneumatic relays, photoelectric cells, timers, and electromagnetic relays. A comprehensive discussion of each of these units has been found to be considerably lengthy and in addition, somewhat basic.

Electromagnetic relays however, deserve further presentation because of their ability to actuate other circuits sequentially and conditionally. They are used widely for interlocking multimotor machines, and are useful for computing, information storage, and general information processing. They can be arranged into logical circuits as illustrated below, and have many other applications which are extensively treated by Kiester, Richie, and Washburn (11).

Control of discrete machine actions can be broken down into statements of logic using the connectives "and", "or", and "not", such as: actuate conveyor "A" when machine "B" and "C" are on. In this example,

Table 1

A listing of pilot devices and typical applications. (Courtesy The Tool Engineer, Vol. 33, December 1954. After Postingl).

Signal	Pilot Device	Basic Operation	Typical Application
Motion Linear	Pushbutton	Insulated button or plunger mechanism is pressed by the operator to open or close a set of contacts.	General, machine tools, etc. Anywhere a circuit is to be initiated by an operator.
	Foot Switch	Similar to pushbutton except operated by the foot.	Same as pushbutton.
	Limit Switch	Lever or rod mechanism is operated to open or close contacts.	Machine tools, automatic machines, elevators, cranes, etc.
Rotating	Limit Switch (Cam Switch)	Rotation of a shaft causes cams to open or close contacts. May include gear box where many revolutions are involved.	Automatic machines, programming.
	Traveling Nut	Nut type mechanism travels along a rotating screw to operate contacts.	Automatic machines, hoists, programming.
	Selector Switch	Knobs, handles, or levers are turned by the operator to open or close contacts.	Similar to pushbutton application.
	Tachometer	Generator (either a-c or d-c) connected to machine. Output voltage represents machine speed.	Regulating systems in machine tools and automatic process lines.
	Centrifugal Switch	Governor, or other speed sensing device, actuates contacts.	Control plug stopping of electric motors on machine tools, conveyors.
Memory	Mechanically-held or latched in devices	Pushbuttons, relays, etc., featuring maintained type contacts respond to a signal and hold that condition until another signal is impressed.	Machine tool processes, automation.
	Relays with holding circuits	Relays lock themselves in with their own contacts when energized.	General, machine tool and processes, automation.
Time	Pushbuttons	Pushbuttons include escapement or dashpot or capacitor discharge to introduce a time delay after the button is operated. Some maintained type pushbuttons include a delay action to convert the button to a momentary type after an interval.	Used in processes where manual operation is necessary and a fixed time delay is still desired. Used to provide maintained contacts on voltage dips and momentary contacts on power failure.
	Timing Relay	Relay includes time-delay mechanism so that contact action is delayed either on energization of the relay or de-energization.	Automatic machines, processing, etc.
Temperature	Thermostat	Temperature actuates bimetal, fluid in bellows or bourdon tube to operate contacts.	Motor overload protection, automatic processes, heating and ventilating.
Electrical Current	Current Relay	Operating coil of relay is designed to function for a particular flow of current through the coil.	Overload protection, load sensing in batch processing systems, etc.
	Contact Making Ammeter	Similar to relay except designed for very low currents (microamps).	Same as current relay.
Power	Contact Making Wattmeter	Contacts are operated by wattmeter mechanism.	Same as current relay.
Power Factor	Contact Making Power Factor Meter	Contacts are operated by power factor meter mechanism.	Automatic control of synchronous motor field. Automatic control of capacitors for power factor correction.
Resistance	Bridge Circuit and Relay	Resistance to be measured is in one leg of a bridge circuit. Relay or other device detects change of resistance.	Temperature measurements by resistance, follow systems, servo systems, regulating systems.
Voltage	Voltage Relay	Operating coil of relay is designed to function at a particular voltage.	Control circuitry.
Fluid Humidity	Humidistat	Element sensitive to humidity operates switch.	Air conditioning.
Liquid Level	Float Switch	Float mechanism senses liquid level to operate contacts.	Automatic processing systems, sewage and waste disposals, liquid level control.
Pressure	Pressure Switch	Pressure of medium actuates diaphragm, bellows or bourdon tube to operate contacts.	Compressors, hydraulic systems.
Vacuum	Vacuum Switch	Pressure of medium actuates diaphragm, bellows or bourdon tube to operate contacts.	Vacuum systems and processes, pneumatic conveying.
Visual Light	Photoelectric Control	Photoelectric cells or tubes initiate sensitive relays or electronic circuits to operate contacts.	Limit switch applications, automation, process lines, printing and register regulators.

relays which are closed by machines "B" and "C" are connected in series (the logical "and" circuit); consequently an output voltage and hence the actuation of element "A" will only occur when relays "A" and "B" are closed. If it were desired to actuate element "A" when machines "B" or "C" were not on, relays "B" and "C" would be arranged in a parallel circuit (the logical "or" circuit) and would be normally closed to accomplish the "not" function.

Consequently relay circuits can be cascaded so that they will actuate or sequence any given element (machine or operation) on the basis of information regarding the conditional state of another operation. The use of sequence controlling relays provides for set-up changes through electrical switching. Fundamentally, relay sequence control is a method of programming a machine for a given operation. Such a program may be permanent, as in the case of the Cross Company transfer machines, or temporary as is the automatic nailing machine manufactured by the G. M. Diehl Machine Works, Inc. The Diehl machine is designed for nailing boxes, packing cases, skids, etc., and provision is made for using one of a number of nailing patterns built into the machine. On the control panel are ten pilot lamps, nine sequence switches, and ten rows of 24 nail switches each. The sequence switches control the number of sequences to be performed, and the nail switches control relays which select the type nails and their patterns. The machine has 24 nailing heads, each with a solenoid-controlled chute to a nail chuck. During each operation of the driving head, the solenoids release nails to the chute for the succeeding operation. At the end of the sequence, the controls reset and repeat the operation in accordance with the number of sequences designated.

Possibly the ultimate in use of relays in a control function is the installation of the New York City warehouse of Judy Bond, Inc., manufacturer of blouses. The control unit for this automated warehouse is called DASAC (12) which is an automatic, selective dispatching unit containing an electromagnetic (relay) memory which accepts orders for items consecutively, retaining this information for future mechanical routing. The general purpose of the system is to select bulk stock from a storage area, and send these items, on demand, to a packaging area where individual orders are assembled and manually packed.

Consisting of 250 relays, stepping switches, and add-subtract counters, the DASAC is the heart of the control system. To operate the system, cartons picked from the warehouse are manually loaded to a main conveyor in the warehouse. An operator, working from a shipping schedule presses one of twenty-three destination buttons on the console panel, which stores this information in the DASAC relays, and subtracts one from the inventory totals stored in the stepping switches. Each carton then moves down a main conveyor to a right angle transfer control point which only allows one carton at a time to enter a distribution conveyor. At right angles to this distribution conveyor are 23 order filling racks. When a carton is released from the transfer control point, it moves down the conveyor and signals its position back to the control unit as it passes each of the entrances to the 23 order filling racks. When it reaches the pre-selected rack, the switch at that location closes the final interlock to stop the distribution conveyor and actuates solenoids operating the conveyor pull-off mechanism. An electric eye scans the 23 entrances to the racks, functioning as an interlock to prevent another release from the right angle transfer control unit until the selection in transit has cleared the distribution conveyor pull-off device.

The carton then moves down the order filling rack, all of which are placed side-by-side to form a gravity feed table 24 feet long and 53 feet wide. When the container reaches the terminal end of this conveyor, it is cancelled out of the inventory retained in the DASAC memory by actuating a limit switch at the end of the rack.

The remainder of the operation consists of manually assembling the order from the picking racks, returning the semi-full containers to the warehouse, and sending the assembled order to packers, automatic sealers, and finally, to outgoing transportation.

This presentation of automatic materials handling, in addition to its demonstration of the control components, also illustrates the concept of centralized control. The DASAC control unit could have been split into separate components each in a different physical location. However, one-operator control would have been hindered with the inefficient walking from activity to activity. The electrical transmission of control information from remote points has facilitated this installation. In general, it is suggested that centralization of control may be worthy of consideration when considering the potential automation of a process.

The significance of relays in control applications then is their ability to form logical circuits, and to sequence operations. They, of course, have other uses such as counting and selecting, but of major importance is their ability to process, store, and operate on, control information.

SYSTEMS OF FLEXIBLE MACHINE CONTROL

In the preceding section, it has been mentioned that control is concerned with processing information. This section will advance the control-information concept further with demonstrations of several systems in which flexibility is built into automatic machines. In some automated units, flexibility has been lost with the installation of specialized machinery and control systems. The cylinder block transfer machine is a case in point. It can machine only cylinder blocks and is a specialized machine with little or no flexibility. How then, can a machine be both automatic and versatile? The Diehl relay controlled nailing machine is an example of a semi-versatile machine in that different nailing patterns can be programmed into the machine. To achieve versatility, it is necessary to provide a means for introducing varying instructions to the system, with the understanding, of course, that the machine is capable of performing these different operations. In systems which will be discussed in this section, a means is provided for introducing varying information in the form of punched tape, templets, contours, manual settings, etc.

Such versatile units are of significance particularly because of the rapid means by which they may be altered for use in other operations. In some cases, it is possible to store the control information in media such as punched tape, templets, or magnetic tape; it then becomes possible to store these "programs" for future use when it is desired to produce another run of the product.

The first part of this section shall discuss those machine systems which perform operations at a specific location, as does a drill press, while the second part is concerned with systems which perform operations at any location, such as a milling machine.

CONTROL SYSTEMS FOR PERFORMING OPERATIONS AT SPECIFIC LOCATIONS. The previously discussed Diehl relay controlled nailing machine is one of the simpler flexible-program machines. Program changes require no physical rearrangement of mechanical components, but only the setting of the appropriate switches to select nailing pattern and the desired nails. Pattern and nail selection are the variables that are controlled by the sequence switches and nail switches; the machine, in effect, has been programmed for a number of different nail patterns and the operator must only select the desired one.

If an operator were assigned to perform the job manually, he would be given a hammer, boxes of several types of nails, and instructions regarding the desired nailing pattern and the particular nails to use. He would then use this information in the repetitious selection of nails, location of the nailing point, and the physical act of nailing. The act of nailing is a mechanical motor action, but the use of the nailing instructional information is the core of both the manual and automatic control systems. The manual and automatic systems differ in that the machine is faster but less versatile. The machine is receptive only to information concerning the nailing patterns of which it "knows". With its relatively limited selection of patterns and nails, the machine, however, surpasses the operator in speed of nailing these patterns. The generality of machine speed versus manual versatility is, it has been observed, broadly true. The optimum combination of human and automatic control (human versatility and mechanical speed) is believed to be the key to a correct control installation. Consequently it is indicated that when investigating a process for possible automation, the functions which require little or no versatility of control should be observed. Also the desirability of sacrificing the existing human versatility should be questioned before an installation is made.

The Diehl machine is restricted to combinations of fixed addresses (or nailing points); the addresses are fixed in certain coordinate positions. The General Electric Automatic Punch Press, used for stamping electronic chassis, is more versatile in that it can locate and punch any coordinate position. The size of holes and their location are the variables which must be introduced to the machine; they are coded and placed in a punched card or tape which serves as the input media to a special purpose, small scale, computer that interprets this information, actuates the devices to position the chassis on two axes and selects the proper diameter hole punch.

It is observed that control system complexity increases with flexibility. This of course, is to be expected; as the machine assumes more of the functions that were previously accomplished manually, it must become correspondingly intricate. In the nailing machine with its narrow range of address locations, control was accomplished with a relatively simple combination of relays; however, in the GE machine, each hole position must be accurately determined, thus necessitating additional control equipment.

With respect to control systems, the Hillyer Automatic Locating and Drilling machine is similar to the GE Automatic Punch Press. Basic control is through a console into which are set the drilling locations desired. Through the use of servo-feedback loops, the cutting head locates and drills the given position. Operator functions consist of clamping the work in place and then setting the appropriate controls on the console. As an alternative information storage and input medium, punched tape units are available so that a number of holes can be sequentially located and drilled without the need of an operator's direct attendance. Multi-piece production is achieved by re-running the tape through the input mechanism.

All of the preceding control systems were those for performing operations at specific locations, or "discrete address" machines; the next classification is that of "Continuously Variable Address" control systems, or those that machine continuously along a set path, such as a lathe.

CONTROL SYSTEMS FOR PERFORMING OPERATIONS AT CONTINUOUSLY VARYING ADDRESSES. Automatic and semi-automatic versatile machines for accomplishing operations along a continuously varying address have been in existence for over a century in the form of contour following mechanisms. Blanchard used one of the first in 1818 for the production of gunstocks; since that time the units have been refined considerable. Pantograph systems, a lineal ancestor of the present contour followers, are those in which there is a mechanical linkage between a model or templet and the cutting tool. Such machines usually rely on manual guidance over the templet, and are currently in wide use. This type control has been especially applied to milling machines which are also termed duplicators, die sinkers, tracer controlled and profiling machines. The die cutting operation is one to which these control systems have been widely applied, with most automobile body dies being thus cut. The desired shape, usually large with many compound curves, is produced in some easily machined material, with a milling machine using this information from the contour to machine an appropriate hard metal with the identical contours.

These contour following systems have been applied to routers, lathes, milling machines, shapers, planers, boring mills, and even in multiple oxyacetylene cutting.

As is the case with all contour following machines, the control information is stored in the templet, and the remainder of the control system is built to insure that the machine accepts and correctly follows this information correctly. The templet then, is an easily fabricated and easily changed vehicle for storing and introducing continuous tool position-information.

Numerical control is a newer and somewhat different means of controlling a machine. Whereas the position-information of the templet is continuous, numerically controlled machines receive their continuous position-information in discrete steps; however, the steps are such that they are less than the machine accuracy and therefore, relative to the machine, are infinitesimal steps. These step-numbers can be stored in a variety of media, such as punched cards, punched tape, magnetic tape, etc., though in many of the recent developments, punched tape has been used. Standard teletype tape has five channels (hole positions) and is rapidly becoming the "standard" for control uses. These five positions (located transversely across the tape) can be punched or not;

through appropriate combinations of holes and no holes, all the symbols of the alphabet, the numerals 0 through 9, and several other characters can be represented. In control uses, only the numerals and several special characters are used.

This information can be used to step drive mechanisms or can be sent to digital-to-analog converters which transform the discrete number-coded sequences to continuous representations.

To probe deeper into this system of machine control, consider a machine table which is to be moved in two directions of one dimension and also started and stopped with numerical control. It is desired that movement be accurate within 0.01 inch; consequently the table can be moved in steps of 0.01 inch (omitting considerations of backlash, lag and other small causes for inaccuracies). Four states need be represented on the input medium, which shall be punched tape: move forward one step, move backward one step, start, and stop[1]. A two channel tape is needed to represent these four states. If the transverse hole positions are designated as 1 and 2, then the following commands can be arbitrarily assigned:

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[1]Actually, only three commands need be represented if the "advance" and "return" commands are wired to start the system. Two channel tape would nevertheless be needed.

Position 1	Position 2	Command
No hole	No hole	Stop
Hole	Hole	Start
Hole	No hole	Advance one step
No hole	Hole	Return one step

When the actuating mechanism received a move command, it could send this signal to either an "advance" or "return" digital-to-analog converter which would convert this pulse to a shaft rotation. The converter shaft rotation could then be amplified through various means to cause a power drive to move the table one increment.

Consequently, if it is desired to move the table forward six inches, the start command and 600 "advance one step" commands would be punched into the tape. If it is desired to return the table 4.8 inches, 480 "return one step commands" would be punched.

There are two ramifications possible which are often utilized in actual control systems of this type. Instead of punching 600 individual "advance one step" commands, an "advance" signal could be given, followed by a representation of the number 600 which would be interpreted by the machine to advance 600 units. The other addition is the incorporation of a feedback loop to check the actual position of the table against the command position.

The above control system is the basis for the numerically controlled milling machine constructed by the Servomechanisms Laboratory of the Massachusetts Institute of Technology. The system is capable of milling any shape in three dimensions. Instructions to the machine are calculated from blueprints and coded onto punched tape. Once the machining instructions are on tape, the part may be duplicated repetitively with no human intervention except that of loading and unloading workpieces.

It has been stated (13) that numerical control is not strictly a metal working technique, it is a philosophy of control that is applicable to many processes such as textile manufacture, paper making, chemical processing, and the manufacture of electronic equipment.

This not only is true of numerical control, it is believed, but generally so of all flexible-programmed machine control systems. Characteristic of those considered are: one, a machine unit which is capable of performing a number of different operations; two, a control system which provides a means of selecting the desired operation; and three, input media which allows the storing of control information and a means for easily altering this information.

This approach, it is suggested, may be of value when considering the automation of a process, i.e. the determination of the different operations that must be performed by a machine unit; an investigation as to how the control information can be effectively stored, in what form it can be introduced to a control system; and finally, an analysis of the various physical systems for processing the control information.

The number of product variations is an important consideration; the more variations, the more operations a machine must be able to perform, or the more human versatility that must be introduced to the system in the form of manual operations to keep the control system feasible. However, it is believed, that for many products, there are enough operations common to all models so that the remaining variations are such that will warrant consideration of a flexible-program installation.

Inherent in a process investigation of this type will be the determination of optimum man-machine control combinations. Most processes, it is hypothesized, are retaining more flexibility than is needed through emphasis of manual operations.

CHAPTER V

THE USE OF COMPUTERS FOR PROCESS CONTROL

The considerations of numerical control in the previous chapters have illustrated the use of computer components and concepts for control applications. Some sources have labeled computers the "key" to the automatic factory (14), though more conservative ones suggest only a potential application. The computers referred to in these statements are the large scale, general purpose machines which have appeared and received much publicity since World War II.

Computers are broadly classified into analog and digital machines. The analog computer is a physical system which satisfies the mathematical laws of the problem variables. In effect, it simulates the problem in another physical system. The analog system can be electrical, optical, hydraulic, etc., or any other physical representation of the problem or system under study. Usually, however, the general purpose analog devices used in computation and simulation are in electronic and mechanical systems.

Digital computers perform computations with discrete digits. Digital computers then deal with numbers in contrast to the analog devices which operate on continuous variables. In their mathematical applications, addition is the basic function of the digital machine, and all other complex computation is described in a logic based on the concept of addition.

Computation, however, is the only significant application for which the devices have been used. Basically, a computer is an information or data precessing device which accepts data in one form and delivers it in an altered form. This is also the requirement for an automatic control system; thus the projected use of computers is for overall control of a multitude of individual pilot controls.

The applications for which computers are used have been enumerated by Harrison (15) as follows:

"1. First, there are those purely mathematical calculations which arise in engineering and physical sciences. These consist of the making of mathematical tables, evaluation of complex formulae ...

"2. A second class of problems ... is a group of statistical or counting problems. An example of this class is the tabulation of the 1950 population census by the Census Bureau.

"3. Logistic applications are a third class of applications. A large scale digital computer is being considered for automatically monitoring a large military supply system involving over 300,000 different items. A computer is required to maintain a running inventory of all the items, to record stock issues and stock receipts, and to keep track of the location of each item in the supply line. In addition, the computer is made to prepare a forecast of future requirements for the various items based on a statistical analysis of their past rate of issue.

"4. A fourth type of application is the pure commercial. Life insurance companies have taken the lead in applying large scale digital computers to their record-keeping and accounting operations. One study, made by one of the largest life insurance companies, involved the processing of six million policies.

"5. Finally there is the class of real time control applications. ... Studies are being made of large scale digital computers as a possible tool for aiding in the scheduling of aircraft traffic at an overcrowded airport. The computer can be made to keep a running record of all planes in the vicinity and, on the basis of this information, to schedule landings and take-offs and to issue flying instructions which accord with the current degree of congestion. This is a real time problem since

> the computer must keep pace with the actual phenomenon which it is studying. Another potential real time control application is the use of a computer to direct an automatic factory or oil refinery. The computer can examine pressures, temperatures, and other critical parameters which affect the process and, on the basis of such readings, control the process so that optimum output is achieved."

These real time applications are the ones in which computers have a potential for industrial process control. The preceding comments of Harrison are primarily with reference to digital machines; analog computers, while having an application in industrial control, do not have all the applications that have been stated above. Inasmuch as there are basic differences in the operation and applications of these two computers, they shall be discussed separately in the remainder of this chapter.

PROJECTED APPLICATIONS OF DIGITAL COMPUTERS

In an automated process, theoretically at least, there will be several control functions: first, initial control information must be fed to the computer, and used to initiate the desired functions; second, information of one phase of the process may affect another phase, and must then be detected, processed and transformed into control information which will optimize the different phases; and third, information must be sensed from all phases to insure that the process is proceeding according to instructions, and if not, suitable corrective control information must be generated from the available data, and fed back to the process to accomplish the desired actions.

The flow processes are particularly sensitive to overall control through the use of computers. One of the major controlling actions is the correlation of a number of individual controllers in accordance with an overall scheme. A computer can be programmed to yield control information for these controllers on the basis of sensed information; consequently, on the basis of combinations of a number of given events, the computer can determine a "logical" and optimum action. However, the *variables of the flow processes are continuous*; the variables as processed by the digital computer are discrete units. Therefore it is necessary to transform the process variables to computer numbers through the use of analog-to-digital converters, and the computer "answers" must again be transformed to continuous variables through digital-to-analog converters. Because of these necessary conversions, and the fact that a digital control system must be a sampled data system (i.e. it cannot continuously observe the variables but must observe, compute, yield and answer, and observe again), some experts have suggested that an analog computer would be of more value in process control. Consequently, the problem of flow process control will be considered more exhaustively in the next section concerning analog computers.

Regarding the automatic control of fabricating operations, a computer would supposedly direct the actions of the process, as in the M.I.T. milling machine, correlate the phases of the process, and test each machine control system for errors and malfunctions, correcting the existing errors and counteracting the future possible errors.

Fig. 7 shows the projected use of a digital computer in such an application; the control units at each step in the process are under the overall control of the computer which generates the necessary con-

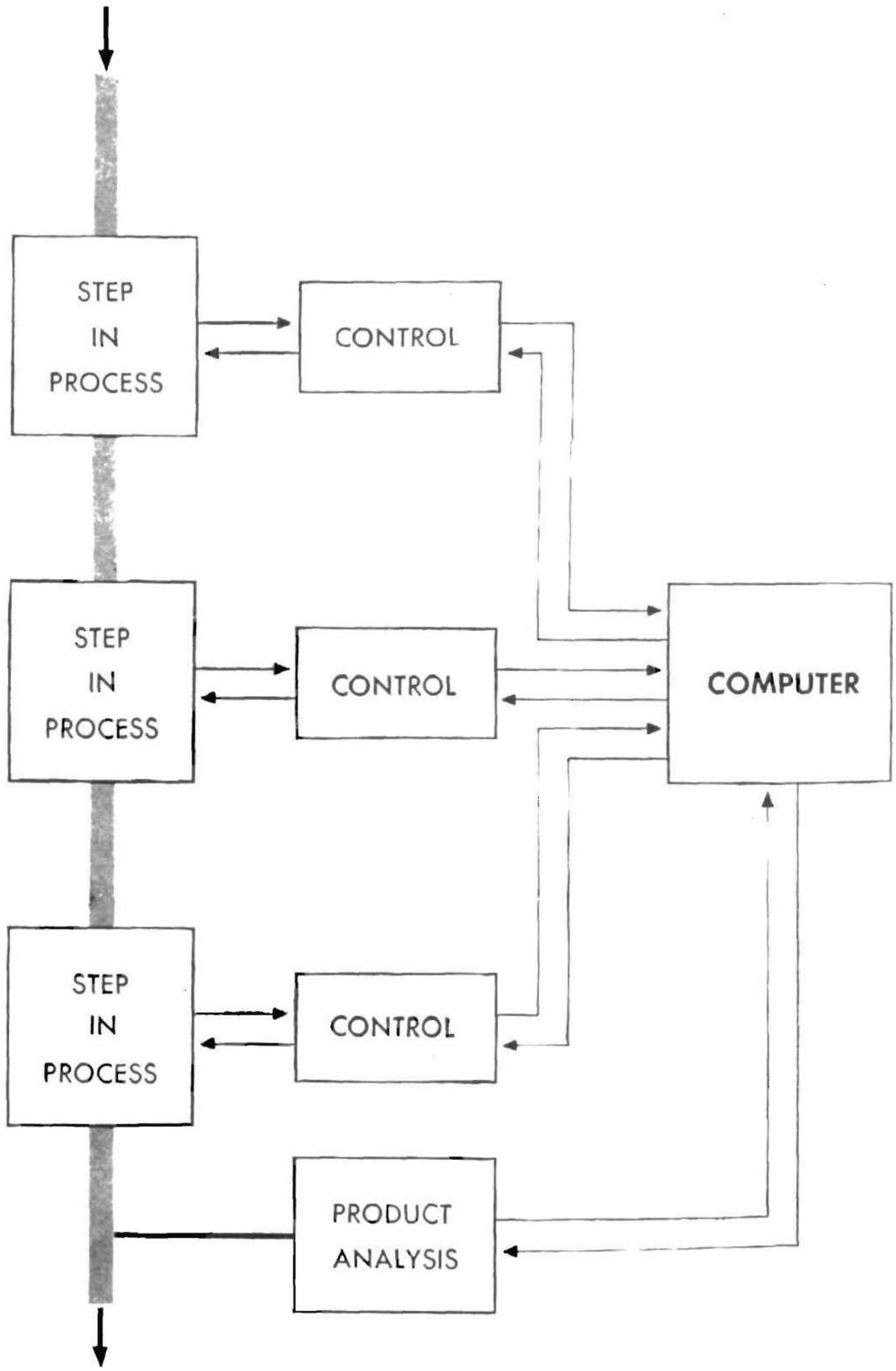

Fig. 7 A projected use of digital computers for industrial process control. (Courtesy Scientific American, Vol. 187, Sept. 1952 p. 81; After Ridenour)

trol information. In addition to direct in-process control, the computer is shown to perform a finished product analysis. This has become known as "end-point control". With the automatic gages currently in use which can detect attribute quality information, it is conceivable that the computer could utilize this data to perform an automatic and continuously-applied form of statistical quality control to immediately correct in-process operations. Realization of end-point control is possibly nearer realization in the flow industries wherein sensing instruments such as infrared analyzers can make a complete analysis of finished product specifications.

An important attribute which makes the computer of particular value is the ability to modify its own instructions on the basis of different phenomena. This is the reason for the claimed decision-making ability of a computer. Instructions are represented as numbers, but when sent to the machine arithmetic section, such number-instructions can be manipulated mathematically. When these altered numbers are returned to the computer control unit they are again interpreted as instructions. Command 46 for the ERA 1101 computer states[1]:

> "If (A) is negative, take (y) as next instruction; if (A) is zero or positive, continue with the present sequence of instructions."

Consequently, the contents of address "y" can contain a different instruction than the next sequential one, thus permitting an alternative

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[1]Where "(A)" means "the contents of the accumulator," (a storage location) and "(y)" means "the contents of address "y" (also a storage location).

choice of action based on the positive-negative state of a number. This instruction is known as a "Sign Conditional Jump" and is representative of other conditional jumps which permit alternative courses of action. While the above illustration permits only one of two courses of action, such conditional jumps may be compounded to allow multiple choices on the basis of other conditions. Thus the computer has the power to discriminate between two values and on the basis of such discrimination a course of action can be selected from several alternatives. For instance, a program such as the following could be accomplished: If a number "A" is larger than a number "B", connect the controls of the unit producing the number "A" to a control pattern ONE. If "A" is less than a number "C", connect the unit producing "A" to a control pattern TWO. If "A" is equal to a value "D", adjust the variables of a unit "E" to coincide with those of unit "A".

Conceivably, if, in a plant, there are enough operations of an automatic and versatile nature, whose variables need continuous scanning and adjustment, such an installation may be feasible.

Cohen (16) in an investigation of the ERA 1103 computer concludes that this general purpose, large scale, computer possesses sufficient flexibility of communication and speed of operation to serve in real time applications of "respectable" complexity. Conn (17) in a quantitative analysis of the problem of real time control submits that rather than adapting a general purpose computer to special purpose control problems, special purpose computers should be designed for specific applications. Current use indicates that general purpose computers may be of more use in the administrative data processing function than in real time control applications. The use of general purpose computers in industrial control would still require the use of a large number of analog-to-digital and digital-to-analog converters inasmuch as many of the industrial variables are continuously varying magnitudes rather than discrete indications. Therefore, the use of analog-digital hybrids, that is, special combinations of analog and digital computers, is a potential form which they may assume in future applications.

In review, it appears that the use of general purpose digital computers for industrial control applications is possible, but that special purpose hybrid computers may be more feasible. Inasmuch as the use of such computers presupposes a high degree of automaticity of the controlled operations, they are, therefore, of doubtful applicability to most medium-sized industrial organizations.

PROJECTED APPLICATIONS OF ANALOG COMPUTERS

As has been previously stated, an analog machine is a physical system designed in such a way that the variables of the system satisfy the same mathematical laws as do the variables of the problem to be solved. In effect, it is a simulator, a term which has been often applied to analog computers. Thus the analog computer can reproduce a given physical system in another representation; a flow process can be simulated electronically to give immediate indications of the result of any combination of variable deviations. Process simulation is one of two major control methods for which analog computers applications have been projected[2]. The other method

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[2]Though only projected applications have been discussed in the published literature, Bibbero (18) states, "Industrial control system schematics now being drawn behind closed doors may mean that this year general-purpose analog computers will be used as process controllers in at least two major plants."

is that in which the computer acts as a centralized controller to replace the individual actions of a number of controllers. This latter method shall here be termed "Direct Process Control."

The application of large scale analog computers has been feasibly considered only for application in the flow processes. The material presented here, therefore, is mainly of projected flow process applications. A final section of this presentation discusses the feasibility of overall fabricating operation control with analog computers.

Before proceeding further, it may be desirable to outline the previous and current methods of flow process control. The initial method of control was purely manual, in which an operator read indicators, compared actual measurements with desired values, and opened and closed valves, rheostats, etc., closing the feedback loop with human actions. By a knowledge of the process and skill, the operator provided anticipation or "lead" so as to make adjustments of process variables on the basis of occurrences which affected later stages of the process. By reference to recorders, the operator integrated the process variables sequentially so as to smooth out fluctuations of the variables under his control.

Much of the operator's time was consumed in reading and recording values; this action has been facilitated by telemetering the variable values to a central location and incorporating "off-normal" annunciators and automatic data logging and scanning systems (19). "Off-normal" systems present an indication to the operator only when variables exceed set limits. Another solution to the problem of effectively presenting masses of data from a complex system to a human operator is the graphic panel, which is a schematic of the controlled system drawn around the process recorders and indicators.

Thus, except for those unrevealed developments, the most advanced state of flow process control consists of the use of individual closed loop controllers, with operating data presented to a supervisor in the most digestible form through the use of data reduction systems and graphic control panels.

THE USE OF ANALOG COMPUTERS FOR DIRECT PROCESS CONTROL. The majority of the individual controllers and regulators now widely used in the flow processes are actually small, special purpose analog machines. In the broadest sense, any essentially continuous transducer, as these controllers are, is an analog device. These units convert the measurement of a primary sensing element into an error signal, change it to an easily handled variable (usually pneumatic or electric), and transmit this signal to a power unit which controls the process through the movement of a valve or other device. The flyball governor, for instance, is an analog controller; it senses variations in the rate of shaft rotation, converts this to linear movement, makes reference to a desired value, and actuates an input on the basis of the difference between the actual and desired values. In the present flow processes, these controllers constitute a large number of individual, expensive, controlling units.

It has been projected that a general purpose analog computer replace the many individual controllers; this, it has been suggested, could be accomplished by connecting the sensing instruments and effector mechanisms to a analog computer to supply the necessary operating data and initiate corrective action on the basis of the computer operations.

Concerning such a system, Bibbero (20) states:

> "Its operational amplifiers can provide all the functions of the controller with complete versatility and, no doubt, better accuracy. Since the usual analogue computer package has approximately twenty amplifiers, and no more than three to six of these are required for a controller problem, the computer may substitute for four to seven conventional controllers."

Thus such a computer as Bibbero describes could control from four to seven variables simultaneously in real time; however, if such an analog computer were used on a sampling basis, a large number of controller actions could be performed in sequence. The number of controllers which a computer could replace on a sampling basis would be dictated by the length of time between samples that the process could operate uncontrolled.

Therefore the use of an analog computer in place of individual controllers for direct process control is one projected application. Such control is also projected for use in combination with indirect control (through simulation), a consideration of which follows.

INDIRECT OVERALL PROCESS CONTROL THROUGH ANALOG SIMULATION. The previous example is one of real time control. The analog computer can also simulate a process action in "faster-than-real time", and thus reproduce process actions in seconds or minutes that in actuality may take hours or days. This simulation of a process in rapid time is one that has yielded many benefits in process analysis, apart from the control function. The quantitative analysis of a flow system to determine the "frequency response", and "transfer function" is revealing to those possessing advanced control knowledge. Even the purely iterative alteration of variables in this manner can be of value. This ability to reproduce a process in a reduced time scale eliminates or shortens equipment down-time needed to establish proper initial controller settings; it is useful in determining the feasibility of new control loops, or in studying the effects of new equipment or emergency conditions on the entire plant. These applications are possible because the computer can be programmed to simulate the action of various types of controller responses and the consequent effects on the process.

For indirect process control, the computer is used to simulate a process in a reduced time scale and to automatically set the actual controller set points at their optimum values on the basis of such simulation or series of simulations. Each controller set point would then be suboptimized; this is the same function as that of the operator who uses judgement and past experience to integrate the various set points to achieve optimal output.

Fig. 8 illustrates this projection with several additional ramifications. The upper figure shows a block representation of existing manual supervisory control, (using individual closed loop controllers and manual set point adjustment). Characteristics of a given lot of raw material are analyzed, and on this basis, process set points are determined; likewise, while the material is in-process, variables are readjusted on the basis of current and preceding phenomenon to produce an optimum yield. Furthermore, the end product is analyzed to determine if the material characteristics are as desired, and if not, additional in-process adjustments are made manually to correct this deviation.

The lower figure is a functional representation of a process simulator used in place of human supervisory control. Data of the variable magnitudes is automatically sensed from the raw material, in-process material, and finished products. This information is sent to a simulation

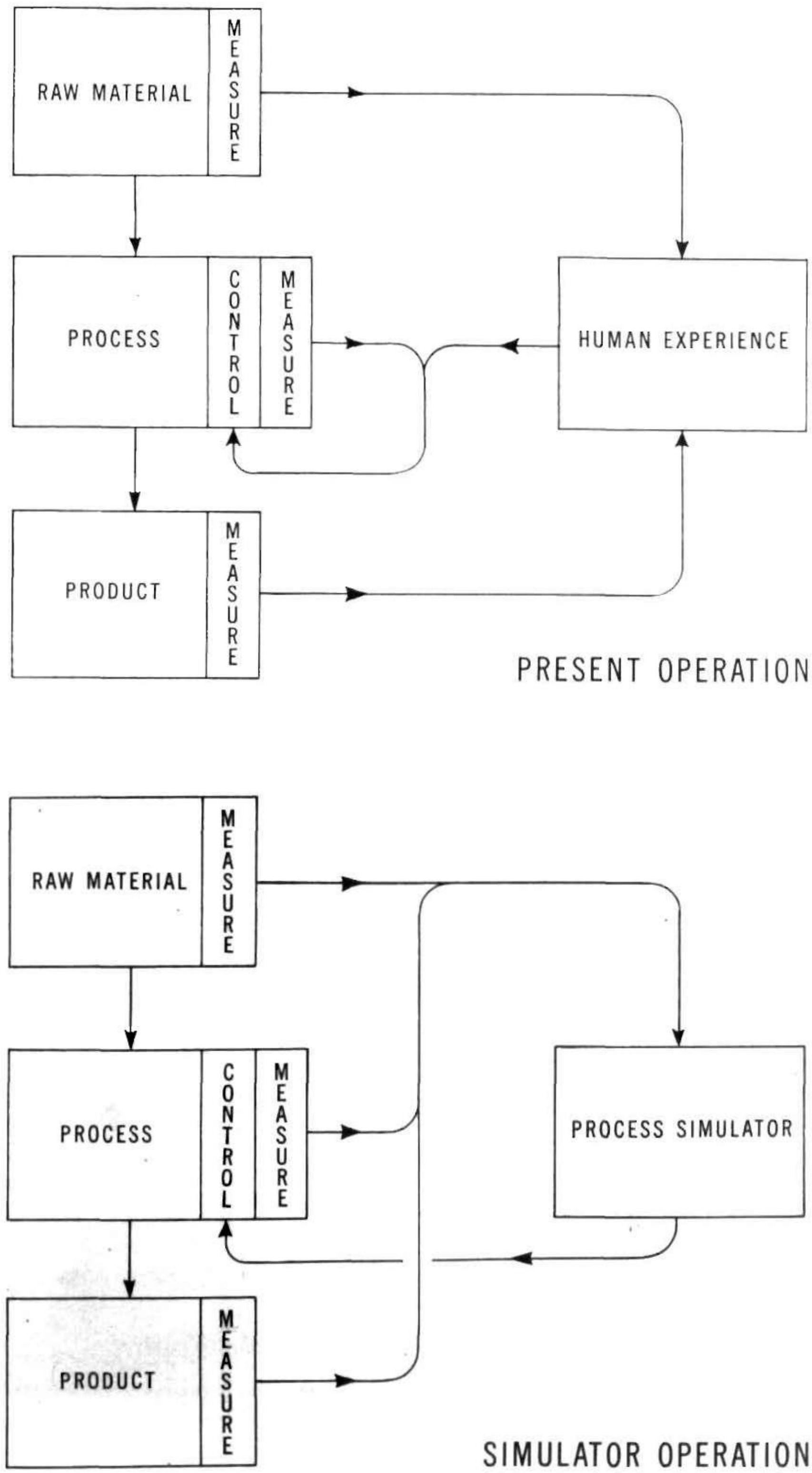

Fig. 8 A proposed use of analog computers for process control through simulation. (Courtesy Automatic Control, October 1954, Vol. 1, p. 10. After Eisele)

of the process which automatically determines the optimum set-points. Theoretically, the simulated set points are swept through a range of values, and as the set points are varied, the quality of the simulated end product will also vary. At some combination of set points, the product will be optimal with respect to some idealized product. In an electrical analog, this optimal product will be represented by a voltage, which when maximized (or minimized, depending on the specific case) will freeze the instantaneous set points and transmit these settings to the real process effectors.

In this illustration, in-process control is not accomplished by individual controllers, but directly through a section of the computer as was described in the preceding section. Consequently this is a combination of direct and indirect control through simulation.

A computer for such an application as this will probably require, in addition to a general purpose unit, special additions and adaptions. It is also conceivable that digital computer components would be used where intricate programming or decisive ability is a necessity.

THE APPLICATION OF ANALOG COMPUTERS TO FABRICATING OPERATIONS.

For individual machine control, there appears to be a potential application for special purpose analog computers for computational purposes. They could be used for generating the harmonic rise for a cam, and involute gear teeth, as is suggested by Cunningham (21). The conventional method of cutting cams involves step by step computation of points followed by compound machine adjustments with the continuous danger that the operator will make the adjustments in the wrong order. Cunningham states that this process could be simplified by the automatic analog computation of a desired curve, with servo actuation of the cutting machine controls.

It does not appear feasible to centralize individual machine analog computations as is possible in direct flow process control, nevertheless, <u>individual</u> analog machine control is potentially of value. Overall fabricating process control with analog computers is not forseeable due to the discrete nature of overall control, but applications in conjunction with digital units appear possible in the form of hybrid computing-information machines.

CHAPTER VI

SUMMARY OF PRINCIPLES

In the previous presentations, several facts relating to potential methods leading to automation in manufacturing processes have become apparent. These facts are here generalized into suggested principles for reference during their application in the following chapter.

To review briefly some of the major points discussed, functional product and process consideration was evolved in the chapter titled "Considerations of Methods and Equipment". The materials handling section revealed that the flow processes possessed one of the most efficient handling methods and it was suggested that these characteristics be adopted where possible.

The chapter concerning automatic control has been fruitful in producing several generalizations; the elimination of manual control is perhaps the most basic, and this in conjunction with an analysis of present operator functions may be of benefit.

Several of the principles have been inserted, not directly relating to the previously presented material, but logically deduced from a general background knowledge of industrial automatic processes.

PRODUCT CONSIDERATIONS

1. FUNCTIONAL PRODUCT ANALYSIS. Before analysis of the manufacturing process, the product should be functionally viewed to determine if there is an alternate product that can be produced in a simplified and automatic manner, but which still accomplishes the same function.

2. FUNCTIONAL COMPONENT ANALYSIS. Examine the component materials of a product to determine the feasibility of substitution, and the effect such substitution will have on the manufacturing method.

PROCESS CONSIDERATIONS

3. PROCESSING MATERIAL IN CONTINUOUS FORM. Material in continuous form is more easily and automatically processed; consequently, as many operations as possible should be performed while material is continuous. Conversely, material in discrete form requires discrete feeding and unloading. Analyze the operations for the possibility of altering the sequence so as to perform them on initially continuous material.

4. ARTIFICIAL CONTINUOUS AND SEMI-CONTINUOUS FORM. If material is received in discrete form, or must be in such form due to the nature of the process, investigate the possibility of placing it in continuous form, in effect, by using indexing workholding fixtures, magazines, or by physical attachment to continuous material.

5. FLEXIBILITY OF TOOLING. When run changes are required, investigate the possibility of using equipment so tooled that it is capable of performing any of a number of operations when so directed by the control system.

6. MINIMIZATION OF RUN DIFFERENCES. Minimize the run-to-run product differences through modular coordination and standardization.

7. SEGREGATION OF SIMILAR RUN OPERATIONS. Segregate those operations common to all runs and perform them on a continuous basis.

8. MECHANICAL FEEDING EQUIPMENT. When operator functions consist only of feeding and stock removal, utilize mechanical bulk feeding equipment and product-designed conveyors for movement of the part to the next operation.

9. MACHINE COMPOUNDING. Where possible, group machinery around a central materials handling unit so as to form an in-line machine and to eliminate repetitive feeding and unloading.

10. LIVE STORAGE OF MATERIAL. Store materials on conveyors or other "live" materials handling equipment where possible.

CONTROL CONSIDERATIONS

11. MANUAL CONTROL ELIMINATION. Use automatic controls where possible to eliminate manual observations and adjustments.

12. ANALYSIS OF OPERATOR FUNCTIONS. Where an operator is performing both physical movement of components and processing control information, these activities should be segregated; the means for automatically processing the control information, and the means for accomplishing the physical actions should be analyzed separately.

13. CONTROL FUNCTION INTERACTION. When the pure control information has been identified, examine the interrelationships with other control functions of the process and determine if an overall control unit can be used or whether the control actions should be limited to that one operation.

14. CONTROL OF FLEXIBLE TOOLING. Isolate the variables causing run changes (i.e. shape of cut material, length of units, etc.) and provide a control system to vary the operating instrument or cutting tool to adjust to the requirements for each run. Characteristics of such flexible installations are: (a) a machine capable of performing a number of different operations, (b) a control system which provides a means for selecting the desired operation, and (c) input media which allow the storing and alteration of control information.

15. CENTRALIZED CONTROL. Transmission of control information to a centralized point is of advantage when human interpretation is required.

CHAPTER VII

PROCESS OBSERVATIONS AND APPLICATION OF PRINCIPLES

In accordance with the objectives stated in Chapter I, and using the knowledge gained from a review and analysis of the published literature, ten medium-sized Georgia manufacturing organizations have been visited and an attempt has been made to apply the suggested principles with benefit. A free reign of thought has prevailed in these suggestions in order to exercise the developed generalizations; the feasibility of the final results can, of course, be finally determined only in the light of economic evaluation.

Regarding the mechanical details of the visits to the ten medium-sized[1], Georgia-owned, manufacturing plants, a policy-making management member was contacted where possible, so that management policies and quantitative data could be obtained. Initial contact was made by telephone at which time the thesis objectives and requirements were outlined, and a date set for the visit.

After introduction to the person visited, the nature of the study was explained in more detail, and familiarity with the concept of automation was queried indirectly. The executive was then asked to what degree his organization had considered automation and whether such consideration approached actual technological evaluation, installation of

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[1]Not rigidly defined. Production equipment investment varied from $30,000 in the smallest plant to $2,000,000 in the largest.

automated equipment or systems or a contact with the published technical literature.

The executive was assured that the firm would not be mentioned by name, but only by a number designation, and that the following requested quantitative data would only be presented in the form of ratios:

1. Annual wholesale value of production.
2. Annual production labor payroll.
3. Number of production labor personnel.
4. Production equipment investment.

From this information, the following ratios were computed to determine their relationship to a potentiality to automate.

1. Production value : Equipment investment.
2. Equipment investment : Number of production personnel.
3. Production value : Number of production personnel.
4. Payroll : Equipment investment.

The process was then observed after which a process description was written in smooth form. The observations for each plant are organized under the headings of "Process Observations", "Management Opinions", "Product Considerations", and "Process Considerations".

PLANT ONE

PROCESS OBSERVATIONS

Plant One is a soft drink bottling plant, producing only one drink mixture in seven identical, but separate groups of machinery. There are no product variations and the process currently possesses a high degree of automaticity.

Returned empty bottles are received at the plant in cases of 24 bottles and are unloaded manually in units of cases from trucks. Cases are either stored or placed on conveyors for immediate processing. The input conveyor moves cases to a bottle unloading station where they are unloaded 12 at a time with a manually operated jig to a positioning table. On the table, the bottles are mechanically aligned in rows of approximately 25 from which point they are mechanically transported to a washing and sterilizing machine on an upper level of the plant. In the washing machine, bottles are automatically spray washed with plain water to remove interior objects and immerses in five successive baths of high-temperature mildly caustic solutions. Finally, bottles are washed with 6 inside and 4 outside plain water rinses.

Caustic solutions and temperatures of the washing tank baths are manually controlled; variations are reportedly slight but are periodically checked by supervisory personnel.

From the washing machine, bottles are mechanically placed on powered product-designed conveyors for inspection and filling operations. After manual inspection of bottles for cracked glass and effective removal of foreign objects, the following operations are performed: syrup filling, carbonated water filling, and capping (crowning).

The syrup filling machine (known as the "syruper") is a continuously rotating circular table over which the filling mechanisms are mounted. Bottles received from the washing machine are secured around the perifery with fixtures, and are filled during their circuit of the machine.

Syrup for this machine is received in drums and is placed in tanks on the floor above the filling machinery. Syrup is then gravity fed to a measuring container mounted on the machine. The measuring unit consists of a cup which dips vertically into the syrup, and after flooding, rises so that no more may enter; simultaneously, a valve is mechanically opened to allow the syrup to flow out into the bottle. After filling and completion of the circuit of the machine, the bottle is shifted by a mechanical transfer device to a carbonated water filling machine known as a "carbonator".

The carbonator, which injects a mixture of carbon dioxide and water, is essentially the same as the syruper except that the filling cycle is longer and the circumference of the machine is larger in order to accomodate the output of the faster operating syruper. As before, bottles are rotated on the circumference of the machine, but are filled through a pressure-tight seal so that the carbon dioxide-water mixture will not effervesce. Fluid input to the carbonator is refiltered city water, cooled to 32° F. and mixed with the carbon dioxide in another unit. Volume of carbonated water filled to the bottle is controlled by utilizing the Boyle pressure-volume-temperature relationship. A reference pressure is set in the control mechanism for existing temperatures to control the volume; the filled bottle pressure and reference pressure are then compared in a closed loop system to achieve the desired bottle volume. A third order control loop is closed through manual setting of the pressure set-point as dictated by the temperature. Temperature and carbonation are manually checked in 30 minute periods to reset the reference pressure, if necessary. Carbonation pressure is a function of CO_2 content and requires infrequent manual adjustment in a separate carbonation unit.

From the carbonator, filled bottles are mechanically transferred to a capping unit (crowner) which automatically positions a cap and crimps it in place to form an air tight seal. Incoming caps are placed into a three foot diameter receptical, unoriented and in quantity, in an upper level of the plant. Caps are mechanically oriented and gravity fed through an enclosed channel conveyor to final positioning mechanisms mounted on the crowner, where they are attached to the bottle. In the event that a bottle is ejected from the machine uncapped, a pawl will inject into the bottle mouth which actuates a limit switch to stop the syruper-carbonator-crowner machine group.

Following ejection from the crowner, the bottles are conveyed to a mixer. The mixer consists of a mechanism which inverts and rapidly rotates the bottle, mixing the carbonated water with the syrup; bottles are then reloaded to the product-designed conveyor leading to a photoelectric inspection device.

The photoelectric inspection unit is also constructed so that bottles ride on the periphery of a rotating table. During the machine cycle, the bottles are spun and then abruptly stopped, allowing the fluid contents to remain in motion; solid impurities in the bottled mixture interrupt a light beam and cause the photoemissive cell to actuate a memory device which ejects the bottle from the conveyor after it has left the machine.

After inspection, bottles are fed to a mechanical positioning unit which aligns them in a four by six pattern for mechanical loading to 24 bottle cases. Cases are fed from the lower plant level, either from the unloading operation, or from stock. From the empty bottle unloading operation, cases are mechanically inverted to remove trash, returned to the upright position, and mechanically conveyed and positioned to receive the pre-positioned 24 bottle group from the case-loading machine.

After loading, the cases are conveyed either to a truck loading area for manual loading, or are palletized for storage.

MANAGEMENT OPINIONS

An executive of Plant One stated that his organization performed a continual technical evaluation of the process for determination of potentially advantageous installations. He also stated that the company would adopt without hesitation equipment or devices which would perform with the same or better accuracy than the current personnel.

The executive further stated that his product had not experienced a price increase due to increased labor or material costs, primarily due to better processing methods, and therefore a liberal attitude was expressed concerning possible process improvement through increased automaticity.

An opinion was also expressed that automation would not cause a serious labor disruption.

PRODUCT CONSIDERATIONS

Functionally, the product of Plant One is a non-alcoholic beverage, sold in returnable glass containers. As is the case with most bottled beverages, the sales appeal of the product is a combination of the drink taste, and the recognition value of the bottle. Functionally, the product is designed for "refreshment", and the sales appeal of the item is created through advertising of the particular trade name. Consequently, a change in either of the two factors of taste or container form would be a disadvantage.

One possible consideration is the alteration of the containers to non-returnable bottles, however, such would not eliminate the need for washing incoming bottles. The company has experimented with larger containers so as to provide more product per container, and consequently less discrete handling per volume of product manufactured. While this does not particularly facilitate the automaticity of the process, it does allow for sales and handling of the unit in larger unit loads.

A functional product change is not considered warranted.

PROCESS CONSIDERATIONS

The process currently makes use of the principle of processing material in continuous form, though there may be an opportunity for additional application which will be investigated. The principle of artificial continuous processing is currently used in the operations on discrete bottles. This of course, is facilitated by continuous run operation.

The raw materials of Plant One are empty bottles, bottle caps, and fluids, and therefore the materials are initially in both continuous and proportions. Agitation could be accomplished either mechanically in the tank or through fluid flow over irregular surfaces.

The current operator functions consist of regulating certain process variables, manual inspection of bottles, physical unloading of cases from trucks, unloading bottles from cases, and maintenance.

Concerning manual variable control, the major operation-controlled variables are those of caustic concentration in the washer, pressure set-point for the carbonator, and several non-critical adjustments. The carbonator set-point could be automatically controlled by a unit which would adjust the set-point on the basis of temperature. Since the ultimate objective of this unit is to control the fluid level in the bottle, an alternative solution is the use of a photoelectric cell (or cells) in conjunction with the present system which would indicate when the fluid level was off-normal, possibly at a centralized control area. Thus instead of periodic checks on the controller set-point, the adjustment need only be made when an off-normal indication is presented.

The centralized control principle may be useful inasmuch as the variables are relatively stable and require infrequent adjustment. With centralized control and off-normal indications, control loops could be left open with manual variable correction on demand. One operator could thus control all the variables of the seven processes.

The operator function of bottle inspection is specifically to remove those bottles emerging from the washer which are chipped or are old and defaced. A secondary function is that of detecting and removing bottles with remaining impurities, though an automatic photoelectric inspection unit also checks the bottles for impurities after filling. The basic function, however, is that of visually determining the acceptability of the bottle. Basic bottle inspection could possibly be accomplished automatically through the use of photoelectric cells to determine the concentration of scratches as a function of the amount of light transmitted through, or refracted from, the empty bottles. Feeler pins could detect whether a bottle was chipped at the mouth or base. Management desires a positive check on this activity and considers manual inspection necessary; however, it is possible to pass only "perfect" bottles with automatic inspection units with manual inspection of those rejected.

Another major operator function is unloading empty bottles from incoming cases. Analysis of the operator function indicates that it requires limited control activity and is primarily a repetitive mechanical operation. One solution is the use of air suction cups to remove the bottles from the case. A bar could be placed across the input conveyor such that it would contact the upright bottles and stop the case. Through the use of a pressure switch on the bar, a limit switch, or a photoelectric cell, a 24 cup suction mechanism could be actuated which would contact and lift bottles from the case to the automatic washing machine table (from which bottles are currently automatically positioned to the washer). After the bottles have been lifted, the stopping bar would no longer contact them or impede the empty case which could then proceed to the automatic cleaning operation.

The possibility also exists of physically inverting the case, allowing the bottles to enter individual conveyors, or to drop to a cushioning element with automatic orientation and positioning to the washer conveyor. It is further possible to alter the washer input conveyor to utilize the case bottle-pattern, possibly in conjunction with the suction mechanism mentioned above.

Regarding materials handling, the principle of storage on live materials handling equipment suggests the storage of unpalletized cases on roller conveyors. Live storage presently exists in some areas but is primarily for movement with short storage period. Such a conveyor system, built much like a railroad distribution yard, could eliminate all manual operations for the warehousing activity and could be coupled with automatic truck loading discussed below. Such a conveyor could be built in three dimensions, using "air-rights", and the control system could automatically designate the storage location for recently finished stock, and specify which conveyor would furnish cases for truck loading; a control system similar to the DYSAC installation discussed in Chapter IV is visualized. In addition, and as a secondary benefit, the control system could automatically count incoming and outgoing cases and thus maintain inventory figures; correct current stock-on-hand would be available at any instant.

Manual loading and unloading of trucks is also vulnerable to improvement even with traditional materials handling techniques. Improved methods at this activity would not only provide for a cost reduction in handling, but would allow faster "turn-around" time for the trucks enabling them to deliver more products and allowing a reduction in the truck fleet. The trucks now used are of a special body design so that cases lie on five levels of the truck body. An alternate body design is suggested to accommodate either palletized loads or one which could be used in conjunction with the cases stored on conveyors.

If roller conveyors were built into the truck levels, transverse to the length of the truck, then cases could be loaded directly from storage conveyors through an opening in the rear of the truck. A flexible conveyor switching and distribution section could be positioned to each of the openings to allow the cases to be automatically loaded from the storage conveyor to the truck. If the truck were longitudinally tilted so that the rear wheels were higher than the front, the cases could roll in by gravity. This same system is also applicable to unloading operations. After the loading openings in the rear of the truck were closed, cases could not roll out though provision would have to be made to preclude the longitudinal movement of cases in partially empty levels. A locking device for the built-in roller conveyors would obviate this movement.

In the observations and analysis of Plant One, it has been found that in addition to the product considerations, the following principles are currently used:

Processing of Continuous Form Material
Artificial Continuous and Semi-Continuous Processing
Intermachine Transfer
Mechanical Feeding Equipment

The following principles have a direct potential application:

Mechanical Feeding Equipment
Processing of Continuous Form Material
Live Storage of Material
Analysis of Operator Functions
Control Function Interaction
Centralized Control

The four operating ratios have been computed:

1.	Production value : Equipment investment	6.51
2.	Annual payroll : Equipment investment	0.36
3.	Equipment investment : No. production personnel	$ 6,221
4.	Production value : No. production personnel	$40,502

PLANT TWO

The operations of Plant Two are divided into two divisions (the Corrugated and Folding Box Divisions). Each of these will be considered separately.

PROCESS OBSERVATIONS

CORRUGATED DIVISION. The Corrugated Division of Plant Two manufactures corrugated containers from Kraft paper. Paper is received by the plant in rolls by rail and truck. Rolls are manually unloaded from the incoming carrier, marked, inventory papers attached, and are then transported by a bridge crane to a recessed-pit storage area. Rate of flow through storage is approximately 175 tons per day.

Paper for processing is selected from the storage pit in accordance with run requirements and placed by the bridge crane on a floor level, recessed roller conveyor for movement to corrugating machinery. There are two corrugating machines used to convert the Kraft stock to corrugated laminate. Three rolls of paper are simultaneous fed into the machine to form the two outer layers and the corrugated center section. The center section is first impressed by a corrugating roller after which the two outer layers are successively glued to the center section. If desired, the board can be creased (in one direction) for later folding operations. The final step in the corrugating machine is that of trimming the edges to size and cutting the board to specified lengths.

The output of these machines is placed on four wheeled dollies and transported to a storage bank to await further operations.

The corrugator is attended by operators who load, adjust and unload the machine. Glue is prepared in a central location and piped to both machines.

Following the in-process storage of corrugated sheets is a bank of machining operations for creasing, printing, slotting and folding the sheets. The machines performing these functions vary in degrees of automaticity and age, but all draw from the bank of materials produced by the corrugator, and are listed below.

Creasing machines further crease the corrugated board, usually at right angles to the creases performed on the corrugator. Cutting devices are integral with this type machine for cutting to final size and shape. The machines are manually fed and unloaded.

A partitioner is used for cutting and slotting partitions for corrugated boxes and is also manually fed and unloaded.

Another machine used in this series of operations is a platen die press which is used for cutting box blanks to final shape. It consists of male and female dies and is hand fed with automatic ejection to a manual wrapping operation.

A paraffin machine has been made by the company for applying wax to corrugated cartons and is also manually fed and unloaded.

A printer-slotter is a combination rotary printing and cutting machine (this unit is also hand fed).

The folder-taper machines are the final type used. These machines fold boxes to final shape and apply tape to the necessary surfaces which close the open edges. Some of the older machines only tape the boxes, with manual folding before insertion, while several of the newer machines automatically fold and tape, though still requiring manual loading and unloading.

Products which are completed in these operations are manually tied in bundles and palletized for shipment. Other products scheduled for additional operations are sent to another storage bank.

Following this second storage bank are several types of stitching machines which vary in capacity and automaticity in proportion to their age. In the older machines, individual boxes are manually fed in the folded position and are stitched with wire staples with the stapling mechanism actuated by the operator. The boxes are automatically ejected.

The newer machines, however, when loaded with a stack of containers, will automatically feed, fold, stitch, and eject. However, these machines are limited to the smaller box sizes.

An intermediate automatic machine is in use for the larger boxes which, though manually fed, will automatically start and stop stitching by the use of limit switches.

Thus the boxes are fabricated from Kraft paper; the corrugated board is processed, cut to size, printed, creased, glued, and/or stitched, and palletized for shipment. These operations conclude the Corrugated Division processes.

FOLDING BOX DIVISION. The products of the Folding Box Division are various types of non-corrugated folding boxes, and bottle and can carriers. These carriers are made to customer's specifications, but usually are of the six-bottle size.

Raw material is received in two forms for the process; flat paper stock, which arrives on skids and is used mainly for folding boxes, and roll stock which is used for the bottle carriers.

Stock is unloaded from trucks or rail cars by fork trucks. Flat stock is stored inside a warehouse area adjacent to the manufacturing area; roll stock is usually stored in the open, and is brought to the process as needed by fork trucks.

For some multi-colored products, a primer coat of an ink-like material is placed on entire paper rolls, prior to their introduction to the process proper.

The roll stock is routed to either a "Kidder Flexographic Press" or a "Mercury Printer-Cutter". Both machines are similar in operation in that they are fed by rolls of Kraft paper and perform a series of multi-color printing operations. The Mercury Printer-Cutter can also apply a final plastic coat to the paper to achieve a quality finish and can cut and strip the products of waste material.

The machines are continuously fed and rolls can be "cut-into" the operation without stopping the machine. This is accomplished by creating a bank of unprocessed paper, from which the machine draws until a new roll of paper is spliced into the end of the used roll. Multicolor printing with each color correctly positioned is regulated by a closed loop control which regulates the speed of the printing rolls. A photoelectric cell is actuated by register marks which the printing action produces. If the register marks are not in the correction position, this information is fed back to a controller which adjusts the printing roller. The platen cutter used in the Mercury machine is also similarly actuated.

Printing is accomplished by a rotary drum with rubber negative impressions. Cutting is performed by a platen die cutting press.

Both machines are highly automatic with the operator functions consisting of loading rolls of paper, and unloading cut and printed cartons, when running in adjustment. Machines must be set-up for run changes. The major alterations for such run changes are changes of the printing rollers, ink colors, cutting patterns, and adjustment of the photoelectric registration control. The major variable during operation is the synchronization of the various printed colors and the cutting action. Spoilage results when one of the colors is in the incorrect position, or if the material is cut out of position. From this point in the process, the products are routed to folding and gluing machines which will be discussed shortly.

In addition to the rotary presses described above, the company has a number of Miehle platen printing presses in varying sizes. These presses print in multicolors from sheets of flat stock and are usually used for relatively short-run folding boxes. Some of the larger presses have automatic feeding mechanisms, but the smaller ones require an operator for feeding. In addition, a skilled operator must be readily available for all presses to insure their correct functioning. The products of these machines are multicolored printed sheets which must be routed to Miehle Cutters for platen cutting. After cutting, the box or carton forms are manually stripped of small bits of paper which the machine is unable to remove. Mechanical equipment for this operation is available but is considered not warranted by management due to the cutting machine age, and expected future replacement.

The Miehle machines have excessive set-up times and are old, one having been manufactured in the late 1800's.

Most of the products of these printing and cutting operations are placed in in-process storage to await further operations though occasionally they require no further operations and are shipped. Following a bank of in-process storage material is a bank of folding, gluing, and window attaching machines.

The four "right-angle" folding and gluing machines used incorporate a transfer unit so that folding and gluing can be accomplished in two directions; straight line gluers are also used, but can only fold and glue in one direction. Semi-automatic feeding mechanisms are employed, but operators are needed to insure correct operation and to feed stacks of material. Also, additional operators must be available to clear the frequent jams in the complex mechanisms of the machine. In addition to the complex-fold machines is a window machine which operates similarly to the gluing machines, but attaches cellophane windows to boxes so that the contents will be visible. Outputs of the machines are usually finished products and are 100 per cent inspected and manually boxed. The cartons of various finished products are conveyed to an operation in which the container openings are secured by a manually operated wire stitching machine. After closure, the boxes are manually separated and palletized. After palletization, the pallet loads are marked for inventory control and are either stored temporarily for shipment, or are sent to an adjacent warehouse for stock.

The major operator functions in this last bank of machines, other than set-up changes, are feeding materials, clearing machine jams, inspection, packaging and palletizing.

MANAGEMENT OPINIONS

A management representative of Plant Two stated that while little had been done in their industry in regard to automation, he felt that it was particularly susceptible. Management stated that they had made a technical evaluation and realized that a major criterion was a volume which would justify investment in automated equipment. One drawback to the potential automation of the process, it was stated, is the complexity of set-ups, and the time necessary to accomplish a run change.

It was further stated that the industry was relatively new, and that machine producers were slow to make changes and creative designs and that no overall thought had apparently been given to automation from that source. It was felt that too many gadgets had been and were being added to equipment in deference to an overall attack.

Generally, management felt that the major deterrents to automation were their volume and job-lot characteristics, and that as soon as the regional economy permitted higher volume, automatic methods would become feasible. Retention of flexibility was considered vital due to nature of their client's demands.

Management did not feel that automation would cause sociological disruptions.

It was also reported that the plant was in the process of shifting from older machinery to higher-volume and more efficient equipment in accordance with a long term plan. It was further revealed that Plant Two maintained its own machine design department and had developed automatic packaging equipment for use by the firm's clients, in conjunction with the company's products.

PRODUCT CONSIDERATIONS

GENERAL. The product function of both divisions of Plant Two is that of furnishing a container for other items, though often these containers serve as a protecting enclosure. The specific nature of the containers of the two divisions will be considered separately below.

CORRUGATED DIVISION PRODUCT CONSIDERATIONS. The containers manufactured by the corrugated division are used in applications which place varying degrees of emphasis on the containing and protecting functions.

Concerning the unitizing or containing function, corrugated boxes are used to realize the advantages of unit handling. There are other methods of achieving this function such as the use of pressure sensitive tape, wire strapping, tieing, or the use of a larger primary container when the corrugated box serves only to contain other containers. These possible solutions are of advantage only to the consumers and not Plant Two which must maintain its market. Another possibility exists in fabricating the existing containers from a material other than corrugated board. A low-priced cloth container, held rigid with a wire framework may prove advantageous as would the use of non-corrugated heavy Kraft paper. Triangular or pentagonal base Kraft containers may prove adaptable to automatic manufacture while still retaining the requirements of rigidity by virture of their shape.

The protecting function entails separating the item to be protected from other items which may damage it. One potential method of accomplishing this is the incorporation of bearing points on the product to be shipped.

If it is required that corrugated board be used, an analysis of its functional properties may be of value. Corrugated board is primarily a structural configuration. In order to achieve this structure and considering the primary operations in paper manufacture, the possibility of extruding pulp into the desired structure is suggested. This possibility will be discussed further in the Process Considerations.

FOLDING BOX DIVISION PRODUCT CONSIDERATIONS. The folding box division manufactures bottle and can carriers and various types of folding boxes according to customers' specifications. Again, the functions of the products can be either protecting or containing, or both. The bottle carriers are primarily containers for consumer transportation, while the folding boxes, especially when used to contain textiles are primarily *for product protections.*

In the case of bottle and can carriers, the desired function is to provide an easily handled unit load, which a consumer will find convenient. In the case of cans, this may be accomplished by an easily broken metal seal between the lips of the cans, with additional clamps at the extreme cans to accomodate a handle. A cord or rope lattice may be another possible solution as would a cloth container. Due to the relative inexpensive cost of paper, these alternatives may not be economically feasible, though technologically so.

PROCESS CONSIDERATIONS

CORRUGATED DIVISION. The function of the Corrugated Division is to fabricate shipping containers, and as the process now exists, to fabricate them from corrugated board. A major difference between the processes of Plants One and Two is that flexibility must be retained to allow Plant Two to manufacture in job lots to customer specifications.

Considering a basic alteration in the manufacturing method by extruding paper pulp to form corrugated board, it is envisioned that paper pulp would be fed from a tank, transformed into a semi-solid state, extruded under pressure through an appropriate gate, and rapidly dried.

While this process has been suggested through functional product considerations, it is noted that it is also in accord with the principle of processing material in continuous form. The raw material for this process is paper pulp which is easily handled in fluid form and can be stored in tanks or vats, and most variables of the process would be those characteristic of the flow processes and would be adaptable to automatic control. Furthermore, the complex mechanical equipment of the old corrugating method would be eliminated as would the need for handling of paper roll stock.

Thickness of the product as well as the internal structure can be altered by changing the extrusion gate, or by switching the pulp flow to another gate, thus allowing for rapid run changes. The raw material, of course would require no changes for run changes. Plant Two produces large quantities of scrap paper in its operations, and with a process such as outlined above the scrap paper could be converted to pulp and re-used.

Regarding the use of a heavier craft paper as discussed previously, the principles of machine compounding, flexibility of tooling, processing in continuous form and mechanical feeding equipment indicate that a unit such as the Mercury Printer Cutter be used. It is envisioned that paper would pass through a rotary printer (with automatic change of printing rollers) through a longitudinal creaser, or a platen cutter with incorporated creasers, and finally mechanically fed to a folder-gluer machine such as used in the folding box division.

The first operation in the existing process, that of unloading and storing roll stock, could be altered to allow storage in a system of routing "tracks" similar to the proposed conveyor installation of Plant One as suggested by the principle of live storage. However, since the rolls are of considerable size and are heavy, construction of such a live storage system would require special construction of some size requiring a large capital investment. In addition, such an installation may not have an advantage over the present bridge crane handling method.

Regarding the individual fabricating operations, and starting with the existing corrugating machinery, the principles of continuous processing and machine compounding indicate there may be an advantage in altering the sequence and equipment of present operations.

In the existing operations, the paper is corrugated, and after corrugation, cut into sheets, creased, printed, slotted, folded and taped or stapled; many of these operations take place in separate machines, each requiring a feeding and unloading operation.

A solution is that of printing the external paper layer before glueing to the center layer in a printer similar to the one used in the Folding Box Division, and feeding the output of this printer into the corrugator. The printer should be built with provisions for indexing or switching printer rollers so as to achieve automatic and rapid run changes (principle of flexibility of tooling). To consider the remainder of the operation after corrugation, it is projected that a platen cutter-creaser attachment on the output of the corrugator be installed. The output of this machine compound is then the printed, creased, and cut box blanks, which require only folding and stapling or gluing for completion (though for some runs provision must be made for the attachment of a fiberglass tear-strip). Two avenues are open for the remaining folding and taping operations; these units can also be included in the corrugator-printer-cutter-creaser compound or the units can be sectionalized. Automatic feeding equipment would be required in both instances, and the decision rests on a knowledge of the cycle times of the machines and the potential failure of component compounded machines.

In each machine element it is desirable that control information be interpreted for each of the individual lot operations, i.e., the machines should be easily and automatically altered for lot changes (principles of flexibility of tooling and control of flexible tooling). A possible means of performing this in one phase of the operation (that of the cutter-creaser addition to the corrugating compound) is to provide two or more cutter-creasers of which only one would be used for any lot. During that lot run, the cutter-creaser (roller or platen) could be installed for the next lot, at the next run change, it would then only be necessary to switch to the new cutter-creaser and its ancillary registration equipment. This switching action can be included in a control system which would sequentially switch all the alterable machine elements to accomplish a change without machine stoppage.

At the terminal point of the hypothetical process the taped or stapled boxes could again be stacked; it is desired to automatically unitize these stacks for shipment. Existing equipment such as the Bunn slant frame tieing machine could be used, or a similar type mechanism, for subunitization. Palletization could be accomplished by an automatic palletizer coupled with the overall control system so as to automatically alter the pallet patterns in accordance with the run changes, and hence package sizes.

Temporary distribution storage is possible by retaining the loaded pallets on roller conveyors after automatic palletization. Live conveyor storage with automatic routing could also be coupled with a master control system to segregate the runs of different products.

The feasibility of these possibilities would, of course, need comprehensive examination, and probably a degree of compromise between manual and automatic operations.

The following principles have been directly applicable in the analysis of this process:

Processing of Continuous Form Materials
Flexibility of Tooling
Machine Compounding
Live Storage of Materials
Control of Flexible Tooling

The following principles are of indirect or potential application:

Minimization of Run Differences
Mechanical Feeding Equipment
Intermachine Transfer
Manual Control Elimination
Control Interaction
Centralized Control.

FOLDING BOX DIVISION. The principle of processing material in continuous form is currently used in the Mercury Printer-Cutter, though this machine is relatively inflexible from the standpoint that run changes must be accomplished through machine stoppage and the physical alteration of some machine elements. The Miehle machines will not be considered since existing equipment surpasses them in automaticity. It is interesting to note that one cause of their less efficient operations is the necessity of handling discrete sheets of paper rather than continuous rolls as used in the continuous printer-cutters.

The function of the Mercury Printer-Cutter type machines is the preparation of the folding box blanks, and is currently performed in an automatic manner; however, run changes necessitate machine stoppage and physical alteration of the equipment. This could be eliminated through the use of flexible equipment and a control system as briefly outlined in the previous section, and as suggested by the principle of flexible tooling. It is necessary to build into the machine those actions which must be altered during a run change, with a provision for selection by a control unit. In this case, the major changes are the printing and cutting actions. For simplification, consider that the machine need only be altered for two different products; theoretically two sets of printing rollers (with appropriate ink connections and valves) and two platen cutters are needed. For run changes, it is then necessary to switch from one printing combination to the other, and a similar switch between platen cutters and register connections. This perhaps is an over-simplification since the printing rollers and platens must be changed due to wear without run changes; nevertheless, a combination of automatic control and manual operations may be feasible with the duplicated sets of printing and cutting equipment, which would provide for equipment alteration without machine stoppage. This would also allow for run changes by a switching action.

The primary concern is the development of a method of altering the printing and cutting information stored in the printing rollers and platen cutter. If this information can be easily and flexibly changed, then a path for automaticity is opened.

Regarding the existing sectionalization of the printer-cutters and folder-gluers, it may be inefficient to compound them due to the difference in their cycle times and because the folder-gluers frequently jam which would cause a disruption of the entire process. The principles of artificial continuous processing and mechanical feeding equipment suggests the integration of these units. The output of the printer-cutter presently requires manual stock collection and unitizing. The use of mechanical equipment for collecting these discrete products is not impossible; if the printer-cutter and folder-gluer groups are not compounded, the possibility exists of loading the products into magazines which would serve both as the in-process materials handling container, and as an element of a proposed automatic feeding installation for the folder-gluers.

Functionally the folder-gluers unite and secure surfaces of the product. Though highly mechanical in nature, they perform the folding-gluing operations automatically; run changes, however, require manual repositioning of deflector arms and other changes.

The folding-gluing operations are complex, and without a product revision or a more complete study of their operation, the highest potential for increased automaticity exists in the feeding and unloading operations.

Feeding, as has been previously stated, could be accomplished by feeding magazines, the magazines having been theoretically loaded at the terminal point of the printer-cutter machine.

In most operations, inspectors remove finished products from the machines, perform a 100 per cent inspection, and pass the products to other personnel who package the finished products in corrugated cartons. If the 100 per cent inspection could be eliminated, the packaging of products would then be a matter of mechanical equipment design and simple control units. Analysis of operator functions has shown that during final inspection, the registration of multicolor printing and cutting must be determined and the alignment of the folded and glued parts must be checked. There is a possibility that these variables could be checked automatically through the use of a photoelectric cell; color registration could be checked in the producing machine by ejecting those products whose registration marks exceed specified limits from a base mark. Photoelectric detection of cutting registration could be accomplished by checking the location of critical colors when the product is positioned in accordance with a reference. Similarly there is a potential to inspect folding registration by checking the alignment of other registration lines. Provision for the ejection of these unsatisfactory products would obviate the need for manual inspection, and would further allow the use of mechanical packaging equipment, which would feed directly from the output of the folder-gluer machines.

After packaging, it is theoretically possible to automatically close the cartons, route them to palletizers, and hold in temporary live storage pending permanent shipment or storage.

In the discussion of the Folding Box Division, the principle of processing material in continuous form is currently used. In addition the following are directly applicable:

Artificial Semi-Continuous Processing
Flexibility of Tooling
Mechanical Feeding Equipment
Control of Flexible Tooling
Analysis of Operator Functions

Other principles of indirect or potential application are:

Minimization of run differences
Machine Compounding
Manual Control Elimination
Control Function Interaction

The following ratios have been computed:

Production Value : Equipment Investment	7.93
Payroll : Equipment Investment	1.12
Equipment Investment : No. Production Personnel	$ 3,024
Production Value : No. Production Personnel	$23,967

PLANT THREE

PROCESS OBSERVATIONS

Plant Three manufactures aluminum entrances. The two major assemblies are the door frame and the door. The door itself consists of a frame into which a glass plate is seated. In addition, several minor assemblies consisting of lock enclosures, panic exit mechanisms, and push and pull bars are fabricated. The operations observed were those of the fabrication of the door and door frame, and the assembly of components into a completed unit.

The plant manufactures custom entrances individually; the basic operations for these products are the same for the standard items, which are produced in lots.

Approximately 200 variations of extruded aluminum shapes are used in the manufacture of nine basic models of entrances, with approximately 80 variations. The aluminum extrusions are first anodized at a location remote to the fabrication building, and are moved to the fabricating operations in accordance with lot requirements. These surface finishing operations were not observed.

The first operation is one of cutting the extruded shapes for the doors and frames to length. After cutting, approximately 75 holes are manually drilled in the door, of which 50 are tapped. Approximately 50 holes are drilled in the frame, all of which are countersunk, but not tapped. Following the drilling operations, the lot is sent to a die press which is used to cut niches in the various members, and where possible, to punch required holes.

Concurrent with these major operations, the fabrication of locks, opening bars, panic hardware, and other miscellaneous units are accomplished. In these operations, a large number of subassemblies can be manufactured in a relatively short time, and in one instance, that of the assembly of lock components, the needed assemblies for a month's supply are produced in several man-hours. Consequently the production scheduling of many of these auxiliary items is primarily for stock, and not closely coupled with the lot in process; the manufacture of certain items, such as pushbars, is more closely related to the lot in process.

After completion of component parts, the doors and frames are assembled with screw fasteners and welding. All assembly operations are manual, though jigs are used extensively for the positioning of parts.

Many intricate assemblies are required, one of which was the assembly of the panic bar mechanisms inside the vertical enclosed members of the door.

After all operations, the completed units are packaged in corrugated paper board which is used primarily for protection rather than the containing function.

MANAGEMENT OPINIONS

Contact was made with the plant manager who stated that his organization had a basic understanding of the concept of automation, but had not followed the developments of automation closely, and had not made a technical evaluation as such. The plant manager felt that automaticity had little application in the processes of Plant Three due to the job-lot type production, and therefore the volume of any lot did not warrant automatic or straight-line production techniques.

He stated that management was progressive, and would give serious consideration to changes which would provide an economic advantage, although he also stated that capital was not readily available for extensive process changes.

Several suggestions were made by the plant manager regarding automaticity of specific operations.

PRODUCT CONSIDERATIONS

Functionally, the product of Plant Three is an entrance which affords protection for the interior of a building. Protective functions are both the prevention of undesirable human entrance, and the isolation of the building from natural elements. There are a number of variations of solid masses designed to perform this function, and the appeal depends on the aesthetic qualities and the cost function of each.

The product depends heavily on the quality of manufacture and the pleasing appearance of the anodized aluminum surfaces for its sales appeal. Consequently, as is apparently characteristic of the medium-sized plants visited, a functional product revision may destroy the existing market to which the company caters.

The remaining alternative is to revise the method of manufacture or materials used to fabricate the product in its present form. Such a possibility exists in the die casting of the various members, though such an approach would not provide the flexibility now required and would not necessarily contribute to the automaticity of the process. An advantageous functional product revision is not apparent.

PROCESS CONSIDERATIONS

The overall function of the process is to produce multi-component assemblies from machined metal elements. The machining of these components is primarily one of sawing, drilling, tapping, countersinking, and die cutting. The principle of similar run-to-run operations suggests the segregation of those operations common to all runs. The above machining operations are common to all except for the variable of a difference in the specific location of these operations. Consequently the use of flexible tooling and the necessary control units to position the cutting tools or workpiece is indicated. Furthermore, the principle of machine compounding may be followed by combining as many of these operations as possible.

Regarding the sawing of extruded shapes to lengths, the specific variable to be controlled is length of the member. The present operator function is primarily one of positioning the workpiece so that the correct length will be cut and actuating the saw. The positioning function is that of determining a discrete address to which the cutting instrument must be directed; this can be accomplished either by indexing the workpiece or indexing the cutting instrument. Since the relative motion of the workpiece and cutting instrument is perpendicular to the movements for lengthwise positioning, the positioning of the workpiece alone would require two dimensional control, whereas the movements of the cutting instrument would require only one dimensional control, in conjunction with a constant speed workpiece feeding mechanism.

Several alternatives are possible in regard to the movement of the saw. The saw can be programmed to cut all specific lengths that are used in the process, or the saw may be programmed to determine any position along the workpiece longitudinal axis, so that any length may be selected and cut. It is conceivable that the saw could be mounted on a track and manually repositioned after the completion of a lot. It is further possible that two or more saws could be so mounted to cut three or more lengths from one long extruded shape.

One method of feeding materials to this programmed sawing operation is that of a manually loaded chain conveyor which would secure the extrusions in position and move in a direction transverse to the longitudinal axis to the saw(s). The cut members could then be either chuted to the next operation, or dropped from the cutting table (though a table is no longer a necessity) to standard material handling containers or special racks.

While the above hypothetical solution is one of the many possible, the major point to be recognized is that the control system must be one which can determine one specific address (that of the position at which the extrusion is to be severed).

The next operations on the workpieces are those of drilling, tapping and countersinking. These are again specific location operations, though the locations are now in two dimensions.

Again the alternative of positioning the workpiece to the cutting instrument(s), or positioning the cutting instrument(s) to the workpiece exists. Theoretically, if the number of cutting instruments were equal to the number of addresses to be operated upon, all the cutting instruments could be "ganged" and actuated when the workpiece is located in a fixed position. At the other extreme, it is possible to utilize only one cutting instrument which can be universally moved in two dimensions to accomplish all of the drilling actions of a given size; such an instrument is the Hillyer drilling and locating machine discussed in the text, though the Hillyer unit is designed for lighter material. Possibly the optimum combination of these two extremes is a combination of the automatically flexible, and the mechanically flexible drilling heads; where several holes are grouped close together, an automatic and programmed drill would cut each sequentially. For holes located some distance apart, it may be of advantage to use flexible, though manually set, drill heads. In this manner, it is visualized, the workpieces would be loaded to a workholding materials handling fixture, and indexed through drilling, tapping, and countersinking operations. Such an arrangement is actually a three station transfer machine, with provisions for flexible location of the operating addresses.

Again, there are many physical solutions to the automatic drilling of the workpieces, but the major control consideration is that of automatically locating the holes in two dimensions. In addition to the location, such a system must be flexible to allow feasible alteration for run changes.

Drilling operations could precede the sawing operations, with the possible advantage of less discrete handling, though it would be necessary to accurately position the workpieces to the cutting instruments with reference to a benchmark.

Both drilling and sawing operations could conceivably be performed at the same time; multiple saw units and drilling heads could be affixed to the same base in such a manner that the drills would penetrate first after which the multiple saws would cut the long extrusion to size. Several technical problems remain to be solved in such an installation.

Theoretically, the workpieces could be fed directly to the press operation by a mechanical feeding device. While various automatic press feeds are available, this operation may be accomplished with less complexity with manual feed and actuation though a more detailed investigation is warranted. Flexible, rapid set-up changes also remain a problem due to the tooling nature of the press.

While only two of the sub-assembly operations were observed, and recognizing that these assemblies are completed in a relatively short time, it is felt that further investigation into the use of dial feeds may uncover common elements which could be advantageously and automatically performed.

Functionally, the purpose of the assembly operations is to fasten the completed components together into an operating unit. Inasmuch as this involves a multitude of three dimensional positioning of many varied parts, the automation of the final assembly phase is apparently not feasible.

In the discussion of this process, the principles which have a direct potential application are:

Processing of Continuous Form Material
Flexibility of Tooling and Control of Flexible Tooling
Machine Compounding
Similar run-to-run Operations

The following principles are indirectly concerned with the process:

Minimization of Run Differences
Intermachine Transfer

Quantitative information was not available from Plant Three.

PLANT FOUR

PROCESS OBSERVATIONS

Plant Four produces paper envelopes and other communication enclosures manufactured from paper.

Raw material is received by the plant in rolls of paper stock. In accordance with lot requirements, the roll stock is cut to sheet size for use in other machines in the plant. The flat paper stock is then mechanically moved, in stacks, to one of five die cutters. Paper is placed on the machine table in one foot thicknesses and is cut by means of a hand positioned die and a press. The operator positions a single die over the stack of paper, and further positions the complete stack under the press, at which time he actuates the machine, drawing back the stack and manually removing the cut envelope blanks after the machine cutting action.

Machines are grouped functionally in Plant Four, the next group being printing presses. Ten printing presses are maintained which are semi-automatic, requiring only bulk feeding and removal. Manual operations include this bulk feeding, minor operating adjustments, and set-up changes. One maintenance operator is assigned to three machines, and one person for feeding and stock removal attends two or three machines. A spot check of several printing presses showed an average of between four and five set-up changes per day. Three presses used by the plant are capable of two-color printing, and one is capable of three-color printing.

Typesetting for the printing operations is accomplished in the plant, with the final lead lock-up impressed in rubber negatives.

If the lot in-process so requires, the printed envelopes are routed to window-cutting machines; the plant has two such machines, one with automatic feed, and the other with manual feed. The size of the lot determines which machine is to be used. Neither of these machines were in use on the day of the visit.

Following either the above, or the printing operation, depending on the lot specifications, letter size envelopes are transported on dollies to folding, glueing, and cellophane window attaching machines. This machine compound is similar to the folder-gluer machines used in Plant Two. In addition, these machines have provision for printing, which is used only occasionally, again depending on the lot requirements. Printing with these units is of lower quality than the individual printing machines.

Once set-up, these folder-gluer-printer machine compounds require only manual unloading, and bulk feeding. Female operators unload the envelopes manually, package to small boxes, and also load the opposite end of the machine when "low stock" is signaled by an indicator light. The major operating adjustment is the addition of glue, which is accomplished by maintenance personnel. The machinery for these operations is complex, and primarily programmed mechanically; set-up adjustments require physical arrangement of components.

For larger manila envelope fabrication, envelopes are sent to a machine which attaches eyelets and metal clasps. Envelopes are fed in small stacks manually to the machine which attaches these units and automatically ejects the blanks. Operations other than feeding are automatic, with the eyelets and clasps being oriented and fed from a barrel feeder. Machinery used for folding and glueing the larger envelopes is older than those previously mentioned. Operator functions are feeding, bulk unloading, and clearing occasional jams.

In another section of the plant, the company makes custom boxes for shipment of its products from corrugated board, and cardboard. Three manually operated machines for cutting, creasing and metal stitching are used in this operation which was of relatively low volume. None of the units were in operation at the time of the visit.

Finished packaged products are moved to a storeroom on dollies and either placed in stock, or are further manually unitized in larger boxes for shipment. Palletizing is considered not warranted in view of the small size of shipments. After final packaging, the containers are hand taped and sent to outgoing transportation.

MANAGEMENT OPINIONS

The president of Plant Four was contacted who related that his organization was following the developments in automation. The impression was made, however, that his reference was to manufacturer's machinery developments rather than custom installations or the functional considerations of the process. The potential loss of flexibility through automatic installations was recognized as a critical factor.

PRODUCT CONSIDERATIONS

Reduced to its most basic functions, the product of Plant Four is an enclosure for information carrying paper which serves to protect the contents, store transmission information, and occasionally as an advertising medium.

There is a possibility of fabricating the enclosures from another material though it is doubtful that an economical substitute for paper can be found.

The folding patterns of the envelopes could be redesigned for more economical or less complex machinery. The current patterns require folding in two directions, however, if the envelopes were cut so that the bottom of a blank could fold up and form the back, folding on one directional folding machinery could be used. The sharp exposed edges of the envelopes may be objectionable and thus negate the practicality of this folding pattern.

The possibility also exists of cutting front and back sheets separately so that no folding is required; this and the above possibilities will be discussed further in the Process Considerations.

PROCESS CONSIDERATIONS

The function of the entire process is to produce envelopes from roll stock paper. The most obviously applicable principle is that of processing material in continuous form. An ideal solution from the standpoint of automaticity, though perhaps not feasible from a practical viewpoint, is that of processing material from cutting to packaging in one long in-line machine compound. This however, presents the characteristic problems of the multi-station continuous machine ... that of complete stoppage in the event of a component machine failure.

In order to effect continuous processing, the envelope die cutting operations could be performed in a manner similar to the printer-cutter operation of Plant Two. In this case, the envelopes would be cut directly from roll stock, which may also allow increased paper utilization. To achieve flexibility, two or more platen cutters could be used so that one or more could be changed while the other was operating.

If desired, the printing functions could be placed in this machine compound before the cutting operations, but this step would greatly increase its complexity, requiring registration equipment and a means for rapid run changes. In that the current printing presses process from four to five lots per day, this addition may not be feasible. A possible alternate to this addition is loading the output of the platen cutter to standard magazines so that these magazines may feed the printing presses. The major operator function for the printing presses is loading. If such magazines could be designed, from sheet metal perhaps, this would greatly facilitate the automatic feeding of subsequent machines. Transportation of magazines between machines could be accomplished by roller conveyors, and live conveyor storage is a possibility.

The window cutting machine function is hypothetically incorporated in the continuous cutter, thus eliminating this discrete operation.

Maintenance of ink supplies and input materials in the individual printing processes may be facilitated by centralized off-normal indicators. The use of magazines reloaded at the printing presses would again facilitate the automatic loading of the folder-gluers.

The function of the folder-gluers is to make a container from a flat sheet of paper. This function could be accomplished by circumventing the folding operations through the use of two sheets of paper glued together, as mentioned in the Product Considerations. It is envisioned that two rolls of paper would be printed and fed to the cutter which would first cut envelope "lip's" from one of the continuous sheets of paper, and apply glue to the other sheet in the outline of the envelope. It is then possible to press and bond the two sheets together, after which the envelopes can be cut from the two sheets. This action would eliminate the complex folding equipment now used, though one fold, that of the envelope flap, still must be made. If this one fold must be made, it is then possible to cut the entire blank from one sheet so that the fold points are the flap and a "fold-up" so that the bottom half of the blank becomes the "back". This would eliminate much of the complexity of the folding machines. Again, this entire method is predicated on the acceptability of such an exposed-edge envelope. The major operator functions in the section of the process in which the eyelets and clamps are attached, are feeding and unloading. Again, the use of feed magazines, and the alteration of the ejection apparatus to feed another magazine would facilitate the automaticity of these and subsequent operations. Though this requires that operators load and unload the magazines, the feeding frequency would be considerably reduced; in addition, it may be possible to devise an automatic indexing unit to sequentially feed magazines.

The use of automatic packaging equipment at the terminal points of the final operations may or may not be of advantage over manual packing; if the packers also inspect the material, volume considerations and the complexity of the necessary automatic inspection equipment may obviate the replacement of these manual operations.

The principle of processing material in continuous form has been the principle of most concern in this analysis. In addition to this principle, others having direct application are:

Flexibility of Tooling
Artificial Continuous and Semi-Continuous Processing
Mechanical Feeding Equipment
Analysis of Operator Functions

Indirectly concerned are:

Minimization of Run Differences
Live Storage of Material
Intermachine Transfer
Centralized Control

Ratios computed for Plant Four are:

Production Value : Equipment Investment	3.57
Payroll : Equipment Investment	0.86
Equipment Investment : No. Production Personnel	$ 3500
Production Value : No. Production Personnel	$12,500

PLANT FIVE

PROCESS OBSERVATIONS

Plant Five manufactures brassieres in lots which are closely coupled with sales demands. An opportunity was presented for visiting the first several operations of the process, which consisted of cutting material from continuous bolts of cloth, and several minor sewing operations.

Raw material in the form of continuous bolts of cloth is received by the firm and is manually cut in lengths and stacked in layers of four or five dozen, depending on the material, and the lot size of the run. A cutting pattern is laid over these stacks. The firm maintains a number of stock patterns on master sheets, which are duplicated for production use. Occasionally hand layouts are required for special lots.

For volume production, standard patterns are laid on the stacks of cloth which are moved to a die cutter located at the end of the layout tables. An operator manually positions dies roughly over the paper patterns, actuates the press, and removes the cut patterns to a table behind him where the patterns are tied into bundles by another operator. The press operator must select from approximately 10 to 15 dies located on the table.

For patterns that do not have the volume required to warrant the use of dies, cutting is accomplished by a manually guided power knife; a skilled operator traces the outline of the pattern and removes the cloth in stacks after cutting each pattern.

From these cutting operations, the patterns are separated according to size and shape (one lot includes patterns for various parts of the final product). Separated patterns are then stocked, awaiting later assembly operations.

In a nearby area, shoulder straps and various pieces of trim are fabricated. Narrow strip material is sewed, cut, and otherwise prepared for later attachment to the finished garment.

An automatic production machine has been designed and assembled by the company's machinist for the sewing of strap material. Ordinary production sewing machines have been altered with automatic feed equipment and shut-off devices which stop the machine when the input material is depleted or when a thread breaks. Strip cloth is fed from a reel mounted underneath the machine, over a cut-off mechanism (which is actuated by the absence of feed strip pressure), through the sewing mechanism, and finally to a container. One operator is required to replace the feed reels of the seven machines and repair the thread breakages. These machines continuously fold and sew the strap and trim material for the garments.

The output containers are moved to a mechanical cutting unit which feeds from about eight such containers and simultaneously cuts the strips to length. The output of this machine is collected by the operators who catch the strips as they emerge and tie them into small bundles for further processing. The trim material is sent to later sewing operations, while the shoulder straps require the threading of a metal length adjuster between long and short pieces of the shoulder strap. This intricate operation is accomplished by handicapped persons to whom the company sends material. Finished material is received by the company from these outside workers in wire hampers, placed in in-process storage, and later transported to final assembly operations on four wheel dollies.

PRODUCT CONSIDERATIONS

Little can be said about the functional utility of the products of Plant Five though a change in the materials and a consequent fabricating methods change may be accomplished. The purpose of the manufacturing operations is to transform cloth into contoured garments which is accomplished by cutting cloth into small sections and sewing them together in order to form a compound curve. If a means could be devised to alter the fiber texture, so that a piece of flat cloth could be stretched or molded into a compound curve, the cutting and sewing operations could be largely eliminated and the process could be perhaps automatically performed.

PROCESS CONSIDERATIONS

In the cutting operations observed, the process function is to separate cloth by neatly severing the fibers in accordance with varying designs. Consequently the variable which changes between lots is directional cutting information (the varying patterns). In the case of the special lots, the cutting information is read from the overlayed patterns by an operator who guides the cutting knife on the basis of this information. In the case of die cutting, information regarding the position of the die and the particular die to be used is also read and interpreted from the patterns by an operator. An analysis of operator functions shows that they are primarily those of interpreting information contained on the pattern, and performing cutting actions based on this information.

The principles of flexibility of tooling, control of flexible tooling, and manual control elimination indicate that a flexible automatic means of controlling the cutting instrument is desirable.

Among the possibilities for the automatic interpretation of this information are automatic line followers which will actuate cutting knives from the information container on the present, or slightly modified overlays. Servo-controlled knives could move in accordance with the signals from a line-following control system. Pattern information could also be contained in media other than paper patterns, punched tape for instance. Numerical control of the cutting knives would provide an extremely flexible system, though possibly one unjustifiably complex.

Using the developed indication of processing material in continuous form, it is theoretically possible to feed the bolts of continuous cloth to a platen cutter which would cut through one sheet of cloth, and perhaps drop the cut cloth patterns through a chute built into the female section of the platen. This however, may not be of advantage since only one thickness of cloth would be cut by each depression of the platen, and the bolts are in relatively short continuous lengths. Also, this method would require frequent platen changes unless the runs could be lengthened or two or more platens were used.

In the strap and trim operations, it may be of advantage to apply automation to the materials handling function by compounding the cutting operations with the automatic sewing machines. As the operation now exists, continuous strips of cloth are manually moved to another location for cutting; if one or more of the cutting machines were attached to feed directly from the output of the sewing machines, handling of materials between these two functions would be eliminated. Present operator functions on the cutting operation are the positioning of new stock to the cutting machine, removing the output of the machine, and unitizing the removed strips into small bundles. One reason for this tieing of straps is to allow an easy count of the material when it is sent to the residences of handicapped operators for further working. This function could be replaced by a counting mechanism attached to the output of the cutter, which could feed to the currently used wire hampers. It is envisioned that an indexing mechanism would move baskets into filling position when the preceding basket had received the desired number of straps. Thus by combining the sewing and cutting units, it is possible to eliminate the manual operations necessary for feeding and unloading of the two machines. It is felt that a more detailed study of these operations would reveal further potentialities.

The principle of functional component analysis indicates that the strap length adjuster should be redesigned to allow this operation to be performed automatically in conjunction with the automatic sewing and cutting operations. Functionally, the adjuster, which is now assembled to the two lengths of strap manually, serves to allow the garment to be adjusted to the wearers requirements. Possibly the use of a small buckle would serve the purpose, and would only require threading and sewing operations on one side of the strap, though buckle holes would have to be placed in the other. Another variation of buckles exist on some men's bow ties which consist of an oval, through which one length of the tie is threaded and sewn, and the other threaded and folded back to buckle into small holes. Further detailed consideration of this function may open an avenue for the automatic performance of an otherwise tedious manual task.

In the analysis of Plant Five, the following principles have a direct potential application

Functional Component Analysis
Flexibility of Tooling
Intermachine Transfer
Control of Flexible Tooling
Processing of Material in Continuous Form
Manual Control Elimination
Analysis of Operator Functions
Mechanical Feeding Equipment

The approximate value of production was not available from Plant Five however, the two ratios which could be computed are:

Payroll : Equipment Investment	6.00
Equipment Investment : No. of Production Personnel	$ 313

PLANT SIX

PROCESS OBSERVATIONS

Plant Six manufactures flourescent light fixtures and the necessary components except for lamp sockets and transformers, which are purchased. The major material used in this process is light gage steel which forms the exterior shades, transverse light deflectors, and the central supporting members. Ten major models are manufactured with approximately 80 variations. All models are produced in lots, with a single production line in use.

The major supporting member for most fixtures is a "U" channel to which are attached the other component parts of the fixture. In other models, a "V" channel is used as the central supporting member; to the "V" channel are attached the transverse members which diffuse the flourescent light. For one model of the "V" girder, the press blanks 141 slots, 14 holes, 12 extrusions, and 16 notches in a 96 inch section. This combined forming-punching operation is similar for the "U" member and the longitudinal side shades, or reflectors.

The transverse members are manually fed to a smaller press in which they are punched and die cut from sheet stock. These units were observed in steel drums in which they were transported to a subassembly area.

All stamped components for a particular lot are accumulated at a sub-assembly and conveyor loading area. The transverse members are manually assembled to a "V" girder; each separate member is manually inserted (with approximately 40 transverse members per fixture), tapped with a hammer to the correct position, and a metal rod inserted in the apex of the inverted "V" to retain the units. After this assembly, the transverse members were slightly deformed to prevent their movement. This assembly, and the side relectors are then manually loaded to an overhead, powered, monorail conveyor with hangers for transportation to a finishing process. In the finishing process, the metal parts are spray washed, phosphatized and rinsed, after which they are etched in a mild bath of chromic acid. The parts are dried, and are at a temperature of 125° F. when the first coat of enamel is applied by operators using spray guns. The components then receive two coats of pure paint without thinner. The paint is cured for 20 minutes at 300° F. in an automatically controlled oven.

These finished parts are then conveyed to a finishing room one floor above the preceding operation in which they are manually assembled with self tapping screws, components (such as transformers) installed, wired, tested, and packaged. Packages are manually palletized, and placed in storage.

Among the operations not observed was one of stripping insulation from the ends of wire leads. A mechanical wire stripper is used, but not continuously since production requirements are met with partial operation. The operation of die casting aluminum socket enclosures was also not observed.

In one sub-assembly, a metal strip is attached to a plastic lamp socket. This operation was also not performed at the time of the visit, but it was stated that management is contemplating the use of a dial feed indexing table and power screwdrivers for this fabrication.

MANAGEMENT OPINIONS

A management member of Plant Six was contacted and his outlook on automation was discussed. The management member was a graduate engineer, and also was acting as production superintendent; an impression was made that he had an above average understanding of current technological developments and stated words to the effect that his organization was pursuing automation applications aggressively. During the process visit, the management member pointed out opportunities for the application of specific automatically controlled equipment. He stated that his organization was currently considering the mentioned applications, but that present volume was insufficient to warrant the installations.

PRODUCT CONSIDERATIONS

Functionally, the product is a supporting and reflecting unit for flourescent tubes. The present standard designs of flourescent tubes provides little potential change in the existing functional design of the product. It is required that they support the standard tubes and efficiently reflect light; this allows little deviation from existing designs.

Much of the work performed on the present components of the fixtures is that of assembly and fastening. If a means of manufacturing components integrally could be devised, many of these operations could be eliminated. Consequently a change in raw material may allow such fabrication; specifically, the possibility exists of molding the central and transverse members from a precolored plastic. This would eliminate manual assembly of these units and possibly their painting. The entire unit could potentially be manufactured by a plastic molding process, as could each of the component parts. Although many of the molding processes are not highly automatic, their use would eliminate many of the current manual assembly operations.

PROCESS CONSIDERATIONS

The plastic molding method discussed above allows the application of the processing of continuous material principle if injection molding can be used. Raw material in the form of plastic granules can be continuously handled and fed to the molding machine. If for instance, the central and transverse members were cast integrally and the side reflectors separately, then the entire painting and surface treating operations could be eliminated through assembly with self-tapping screws,or other fasteners would be required. Other components such as sockets and transformers would still have to be mounted. Injection molding, while automatic in many respects, would require the attention of an operator.

Concerning the existing process, there is an opportunity to use the principles of continuous form material and mechanical feeding equipment in the press operation for the stamping of transverse members. An automatic feed for this press would be facilitated by using roll stock instead of sheet stock. The roll stock could be fed to the press continuously without attention by indexing the material mechanically; the controls for the index and the press actuation would necessarily have to be coupled. The physical relocation of this press to the assembly area would also facilitate materials handling though not directly contributing to the automaticity of the process.

The transverse deflectors are used for many models of fixtures, while the central member and side deflectors are not; consequently the runs for these items are relatively short, and in addition to the inherent difficulties of die changing for the press on which they are fabricated, the automation of this operation is apparently not feasible. The principle of modular coordination may be of use in reducing the number of run changes and hence increasing the potential for using automatic equipment in this operation.

The first assembly operation is one of manually assembling the transverse members to the central girder. In the existing fixtures, slots are cut in the central member and the transverse units are inserted and secured with a rod in the apex of the "V" girder. The insertion of the rod makes machine assembly particularly difficult. The functional component analysis principle indicates each of these units should be examined for possible redesign so as to facilitate machine assembly. The function of the slots is to establish the position of the transverse members and in conjunction with the rod, to retain them in place. An alternate means of fastening these units is to blank the transverse members so as to fit "around" the V member rather than to slot into it. The transverse member could also be blanked with lugs on each side of the "V" to fit into appropriate openings in the central girder. Small slots could be cut into the apex of the central "V" girder to position the transverse members. Consequently the retaining rod could be eliminated with the retaining function now accomplished by a force fit of the transverse member to the girder (being retained by the lugs). It is now conceivable that the transverse members could be fed to a positioning unit which would force them on the transverse member either serially as the central girder indexed past the fitting station, or all at the same time with a number of fitting units mounted over the girder position.

After this sub-assembly, all units are mounted on an overhead monorail conveyor for automatic surface treating and manual painting.

Functionally, the painting operations are designed to protect the metal surface and provide a pleasing appearance to the product. There exists the possibility of eliminating the painting operation completely through the use of anodized aluminum or other similarly treated metal though this may cause undesirable reflective characteristics of the fixture.

Operator functions are basically those of positioning the paint spray to unpainted surfaces of the parts. The possibility exists of utilizing an electro-static spraying unit for this operation; management is currently aware of this possibility, but, it was stated, volume considerations prohibit the installation. As was discussed in the Product Considerations, the use of pre-colored plastic would eliminate the painting operations completely.

Regarding the assembly of components, this operation is currently performed manually on a production line basis. Run changes necessitate considerable flexibility in these operations and the principle of flexible tooling would direct attention to an extremely complex machine. A method of feasibly automating the assembly operations is not apparent.

Principles which have a theoretically direct application are:

Processing of Material in Continuous Form
Functional Component Analysis

The ratios of Plant Six are as follows:

Production Value : Equipment Investment	10.0
Payroll : Equipment Investment	0.9
Equip. Investment : No. Production Personnel	$ 2,857
Production Value : No. Production Personnel	$28,571

PLANT SEVEN

PROCESS OBSERVATIONS

Plant Seven rebuilds automotive generators, carburetors, clutches, brake shoes, distributors and starter mechanisms. These units are received from automobile repair firms and other sources in used condition. Units are received in the plant from trucks, and are manually handled in the transit material handling area. Units are then segregated, degreased and subjected to other chemical treatments to remove dirt, rust, and other foreign objects. Parts are manually placed into and removed from the various baths. Some parts are further cleaned in tumbling mills and sandblasting machines before disassembly operations, while others are disassembled first, and cleaned afterward.

Disassembled parts are cleaned, refinished or replaced as necessary. All disassembly and assembly operations are manual. Powered mechanical equipment was used in several operations, but without automatic controls.

After reassembly and testing, the parts are manually moved to a packaging area, packed, and placed in stock for shipment.

MANAGEMENT OPINIONS

The one management member of Plant Seven professed unfamiliarity with automation, and stated that he had not considered revising the process to achieve increased automaticity. Observations indicated that management was technologically conservative.

PRODUCT CONSIDERATIONS

Plant Seven is unique in that its incoming products determine the specific nature of the finished product, and conversely, the finished product determines specifically the nature of the required raw materials. For example, if the process function is to rebuild a Ford generator, the raw material must be a used Ford generator; also if a Ford clutch plate is received as raw material, the organization has no choice other than to rebuild that model clutch plate. Consequently, functional product considerations suggest no possibility of substituting another product which will perform the same function without altering the incoming material.

PROCESS CONSIDERATIONS

The process can be divided into the following operations: cleaning, disassembly, additional cleaning, refinishing, reassembly, and replacement of unsatisfactory parts. Due to the lot production and the potential variations within the lots, the process requires a high degree of flexibility. Nevertheless, the principles of artificial continuous processing and similar run-to-run operations indicate that there may be a potential for segregating those operations which are identical for all lots and performing them on a continuous basis.

Of the six major operations of the process, initial cleaning and some of the recleaning operations are common to all products; the operations are currently performed by manually immersing the units in cleaning and degreasing baths and sandblasting units.

It is conceivable that products could be loaded into wire baskets attached to an overhead power conveyor for continuous transportation to and immersion in the chemical solutions. The overhead rail can, of course, be designed to dip into each of the baths and to remove the baskets after traversing the length of the bath. Rather than a continuously moving conveyor, an indexing conveyor, or a combination of an indexing and continuously moving conveyor could be used; the use of one of these methods depends on the length of time the products must remain in the baths, the space available for the baths, and the volume of products to be cleaned.

Either prior to or after the cleaning operations, the products could be automatically segregated, if such is necessary, by weight. If each type product has a weight range which is different from any other type product, it is possible to design a distribution system which would channel each type unit according to its function. Distribution information would be detected from a scale and would cause a distributing effector (such as a channeling arm on a series of conveyor entrances) to channel the part to one of a number of conveyors or to open a drop chute to a container.

A survey of the remaining principles has suggested no indications for potential automaticity of the assembly operations; a thorough analysis of the operator functions, and in general, a more detailed observation of these operations, would be of benefit.

In addition to the consideration which Plant Seven should give to automatic installations, it has been observed that traditional industrial engineering techniques could be of benefit and management should also investigate these possibilities.

The principles which have theoretical direct applications are:

Artificial Continuous Processing
Similar Run-to-Run Operations

Operating ratios calculated are:

Production Value : Equipment Investment	10.0
Payroll : Equipment Investment	1.95
Equipment Investment : No. Production Personnel	$ 889
Production Value : No. Production Personnel	$8,900

PLANT EIGHT

PROCESS OBSERVATIONS

Plant Eight manufactures writing instruments. Various models of mechanical pencils, ball point pens, and fountain pens are fabricated from plastic, metal, and rubber. Only observations of the manufacture of ball point pens and mechanical pencils were made. The components of the pens and pencils are contained in a cylindrical barrel which is made of plastic. Metal trim, pocket clips and points are attached to the barrel exterior and other operating components are contained inside the barrel. The majority of the interior parts for the mechanical pencil are metal, while those of the ball point pens are metal and plastic. Production for most models is continuous.

Manufacture of the plastic barrels is performed in automatic injection molding machines. Thermoplastic resin chips are received in pallet loads in the molding room and batches of these chips are loaded to machine feeding hoppers. The raw material is automatically measured, heated, and injected into the molds. Operator functions are primarily those of loading of the hopper, when required, and unloading material when the mold opens. These functions vary according to the model of the machine; in some units, the barrels are automatically unloaded and the operator removes the runners and sprues. In others, the operator must unload a battery of barrels while still attached to the sprues, and load metal points to the mold which are to be molded integral with the barrels. Also manufactured by injection molding are the plastic ink tubes used in ball point pens.

In those cases where the barrels are not automatically severed from the runners, they are manually broken at the runner gate; the operator also performs a 100 per cent inspection and discards the unsatisfactory barrels for reuse in the molding process. In other instances, it is necessary to saw the top of the barrel to remove the runner; this is accomplished with a special cut-off machine. An operator positions four barrels (attached to a runner) to a workholding conveyor which moves the barrels in correct orientation through a saw. Individual barrels are then drop-unloaded to another operator who inspects the units. All scrap and rejected parts from these operations are ground into chips for reuse.

Most metal parts are blanked, drawn and formed in presses. The press operations are characterized by automatic feeding of coil steel and automatic ejection of scrap and finished parts. One operator tends a number of presses, the major operator function being that of reloading coil stock. In one press operation, metal eraser receptacles are formed and rubber erasers are assembled to the receptacles, both being fed to and positioned by a dial feed. The output of the operation is finished eraser sub-assemblies, ready for final assembly.

In addition to the press operations various other units of specialized machinery are used; among them is an automatic spring winding machine, automatic screw machines, and units for producing the ball for the ball point pens. Again, the machinery is characterized by automatic feeding and ejection of parts with the major operator functions consisting of bulk reloading and inspection.

The ball producing process differs from the remainder of the metal fabricating operations since the machining time is relatively long for a physically small volume of products. Raw material for the balls is coiled stainless steel wire which is automatically chopped into short lengths. These cylindrical sections are manually fed to special grinding machines, which through abrasive action, reduce the cylinders to minute balls. The output of these machines are checked in a go-no-go gage for correct size; those with the required attribute are placed in a rotating hopper containing jeweler's rouge and kerosene for one week, followed by an additional week in a lime solution. These operations polish the surface and remove many of the scratches caused by machining. Defective balls are detected and removed by a 100 per cent optical inspection.

After fabrication, metal parts are cleaned and certain ones electroplated. The cleaning operations are primarily degreasing while those parts to be electroplated are subjected to further preparatory chemical treatment. For cleaning and degreasing, parts are manually placed in rotating tumblers containing a cleaning solution, and are removed after a given interval.

Parts to be electroplated are manually mounted on electrically wired "trees" which permit current flow through each part; trees are dipped in acid baths and electroplated with either nickel, copper, chrome, or gold, depending on the model for which they have been manufactured.

Certain other component parts are purchased, all of which are 100 per cent inspected before use. Except for printing company names and advertising on the barrels of pens and pencils so ordered, the remainder of the operations are those of assembly.

In the assembly of ball points, the ball-less points are oriented and fed to a rotating table of a multi-station machine from a vibrating hopper; the points are positioned in a workholding fixture and as they travel between machine stations are drilled, counterbored, and flat surfaces are ground on the point end. The stainless steel balls are gravity fed and automatically inserted in the pen point at one machine station. The end product of this machine compound is the completed point, ready for assembly to ink tubes.

Ink filling and capping of the plastic tubes was not observed, but it was related that automatic machinery is used for this operation also.

The metal and plastic components of the various models of ball point pens are then manually assembled, utilizing mechanical equipment in some instances to assist the operations.

The mechanical pencil components are similarly manually assembled; the lower-priced pencils are assembled on a production line basis, using a work-holding conveyor for movement of the pencils from operator to operator. Again, some mechanical equipment is used to assist the operators. For other model pencils, assembly is on an individual basis.

After fabrication, products are manually packaged in a variety of containers. Most products are mounted directly on advertising placards though some are placed in small containers. Packaging of extra lead for pencils is semi-automatic. One of two operators feeds boxes to a packaging machine while the other manually assembles lead to wooden trays and feeds this unit to the machine. The machine then encloses the trays of lead with a cardboard box. The details of the packaging operations were not observed in further detail, but they were apparently dominated by manual operations.

MANAGEMENT OPINIONS

A policy-making management member was contacted who stated that his company had made technological evaluations of their process with regard to automation and was agressive in making automatic installations. However, the opinion was stated that automation as a concept was not unique, but only an acceleration of automaticity.

It was also stated that the philosophy that automation or increased automaticity would cause a sociological disruption was faulty, and that the end result of such installations would be generally beneficial.

PRODUCT CONSIDERATIONS

The products of Plant Eight are writing instruments of various types. Their function is to leave a visible trace on a writing surface. The ball point in pens has been an advantageous functional change which is amenable to automatic manufacture as are the recently developed "liquid lead" ball point pencils. Further functional alteration is not apparent, though alteration of the mechanical characteristics of the existing units is a potential for an advantageous change. It has been related that the management of Plant Eight is aggressive in discovering and making these changes.

PROCESS CONSIDERATIONS

The machinery of Plant Eight is now functionally grouped; the principle of machine compounding indicates that the grouping of machinery into a multi-station in-line machine system should be examined. The present functional machine grouping is a contributing factor which prevents feasible automatic handling. Since production is continuous for most models, even a production line grouping with automatic intermachine transfer of parts would facilitate process automaticity.

Starting with the first actual operation, that of injection molding, it was noted that plastic chips were stored in bag form and moved from storage to machines on pallets. The principles of processing continuous form material and live storage suggests that plastic chips be transformed to continuous or bulk form at the earliest stage possible. A method of doing this is the breaking of the discrete bags on receipt and storing the various grades of plastic in large hoppers which could feed directly to the molding operations (either to the machines themselves, or to some central location in the molding area from which machine-hopper loads of plastic could be obtained, thus eliminating the manual handling of bags and pallets). If each machine is used for the production of one model and uses only one color of plastic continuously, then it would become feasible to feed the bulk stored material directly to the machine.

As has been previously stated, it is conceivable that the output of the molding machines could be automatically positioned and fed to the succeeding operations.

Regarding the electroplating of parts, the existing method is that of a batch process in which a number of parts are mounted on electrically wired trees. The function of this mounting is to provide an electrical connection to each part and to further provide a unit handling device. The parts in discrete form, of course, have no inherent electrical connections, though they do while in continuous form. Discounting the possibility of electroplating the coil stock before manufacturing operations, it is nevertheless possible to again place the discrete units in continuous form after manufacture by spot-welding a wire to a surface which will be hidden after assembly. These units could then be continuously passed through an electroplating solution with the connecting wire furnishing the current to each component. If light welding equipment is used, such as that employed in the welding of dental bridges, then these welds could be broken from the wire by an automatic shearing action. Theoretically, wire could be used for several cycles;

after receiving an unsatisfactory amount of plating itself, the wire could be placed in the electroplating process to recover the metal which it has absorbed. An alternative to this method is to retain a segment of the strip stock as a connector for the various products. That is, rather than blank each unit from strip stock, retain a thin continuous connector between each item. The products could then either be immersed in the electroplating solution continuously or in batches but without the tedious manual mounting. After plating, the parts could then either be severed by a blanking or shearing operation.

Regarding the existing manual assembly of the mechanical pencils, a workholding materials handling conveyor is now used to move the pencils between manual assembly stations. This operation is very adaptable to automatic assembly, in part if not in whole, through the use of a rigid indexing workholding conveyor moving between automatic assembly stations; the assembly operations are primarily those of positioning for which existing orientation and feeding equipment is now available. The design of the overall machine compound, of course, would necessarily be of a special nature. The observed assembly operations of the other models of pens and pencils are also manual, but without the continuous materials handling unit. It is technologically feasible to perform these assembly operations automatically, particularly in the case of the ball point pens, though volume considerations may preclude the investment necessary. As was observed, one phase of the ball point operation is presently automatic, that of the processing of the point and the assembly of the ball and point. These considerations employ the principles of artificial continuous processing and machine compounding.

Principles which have a potentially direct application in the automaticity of Plant Eight are:

Functional Component Analysis
Processing of Continuous Form Material
Artificial Continuous Processing
Machine Compounding
Live Storage of Material
Intermachine Transfer

An analysis of operator functions may also indicate possibilities for the use of automatic equipment.

Data for the computation of operating ratios for Plant Eight was not available.

PLANT NINE

PROCESS OBSERVATIONS

Plant Nine manufactures a toy consisting of a wooden paddle connected to a rubber ball by a thin strand of rubber. The entertainment value of the toy consists of successively hitting the ball with the paddle.

Rubber balls and strands are purchased by the organization and assembled; wooden paddles are fabricated and assembled to the balls and strands. Raw material for the paddles is received in the form of rectangular plywood sheets with dimensions of approximately one by three feet. Fifteen of these sheets are nailed together and the uppermost sheet is manually marked with the pattern of the paddles to be cut therefrom. These fifteen layer blocks are then transported on four wheel dollies to a bandsaw where they are manually cut in accordance with the pattern previously penciled on the top plywood sheet. The sheets are nailed in such a manner that the paddles can be freely removed after the sawing operation.

The second operation in the process is that of sanding the paddle edges to remove the rough areas caused by the bandsawing. The sanding operator positions the paddles to a rotary sander. Paddles are then either manually spray painted (to become the "Deluxe" model) or are printed unpainted with decorative designs (for the "Custom" model). After spray painting, the deluxe models are also printed.

Printing is accomplished in two one-color platen presses which print the trade mark of the toy, the manufacturer's name, and a decorative design. Operator functions are those of feeding and removing paddles between platen indexes.

During these operations, the rubber strands and balls are assembled by inserting the rubber strand through a punctured hole in the ball. This is performed in a fixture in which a crocheting needle is mounted in such a manner that an operator can drape the rubber strand over the niche in the needle and push the entire ball over the needle so that the ball is punctured and on removal the rubber strand is retained in the puncture hole. The strand is retained by the recompression of the ball.

The rubber strand is then manually stapled (with a production stapler) to the center of the paddle. The stapling operator winds the strand around the paddle handle preparatory to packaging. Units are manually packaged in corrugated containers.

MANAGEMENT OPINIONS

A policy making management member stated that he was unfamiliar with automation though his company was presently developing automatic machinery for use in the process. He stated that a prime cause of Plant Nine's interest in automatic machinery was due to pressure to reduce labor cost. The increase in the minimum wage, it was stated, gave further impetus to this interest.

PRODUCT CONSIDERATIONS

Functionally, the product of Plant Nine is an instrument of entertainment for children. There are many such instruments conceivable of course, but each is unique in that it is different, and sales are predicated on the unique qualities of the toy. A functional product change involves the manufacture of a different toy, which may not be desirable.

The present toy may be produced in a more automatic manner by substituting materials. The paddle could be completely manufactured in a plastic molding process in one operation; the designs and information now printed on the paddle could be molded into the paddle, and the marking, sawing, sanding, and much of the materials handling would also be eliminated.

It may be possible to blank paddles on a press if a material with the required characteristics could be developed. This type operation would be in accord with the principle of manual control elimination (sawing) and may allow the use of the principles of processing of continuous form materials or mechanical feeding equipment.

PROCESS CONSIDERATIONS

Concerning the functional material change discussed above, it is possible to use an injection molding machine to produce the paddles. Several principles are involved in this operation paramount of which is that material could be maintained in live storage in hoppers and continuously fed to the molding machine as discussed in the process considerations of Plant Eight. Painting would be thus incorporated in the primary fabricating operation, in effect, since colored plastics may be used, as would be the printing operation since the information now printed could be molded into the paddle face.

While the investment necessary for an injection molding machine is considerable, more than half of the labor operations would be eliminated. In the final analysis, these savings and the increased cost of raw material must be taken into account to determine the feasibility of the process.

The second alternative posed in the Product Considerations is that of blanking the paddles from a suitable material. While no such material is apparent to the author, the matter is worthy of research since several operations could be eliminated and the possibility of automatically feeding the blanking press would enhance the automation potential of the process and may reduce fabricating cost.

Concerning the existing process, the first operation is one of entering control information (patterns) to the plywood sheets. There are several alternative methods of doing this, one of which is to store the cutting information in the cutting instrument; that is, in the case of blanking, the storage of the pattern to be cut in the die itself. Also a saw feed table could be designed with a two dimensional control system which would feed workpieces to the saw in accordance with a stored information device, such as a cam or punched tape. A less sophisticated method of introducing control information is the automatic printing of patterns on the plywood sheets. If volume does not warrant the purchase of a special printing press, a large manually operated rubber stamp would constitute an improvement over the present method, though it would not be an automatic operation. Both the decorative designs and patterns could be simultaneously printed on the plywood sheets though the possibility exists that the pattern outlines may become out of alignment during the nailing and sawing operation. However, there is no reason why the decorative material alone could not be printed on the sheets before the sawing operation so as to reduce the number of discrete units handled into and out of the printing press.

These operations could be performed automatically by using the principle of artificial continuous processing. It is envisioned that a mechanical feeding unit could feed unnailed stacks of plywood to a product-designed conveyor which would positively position the sheets and move them under printing rollers. A counter could determine the fifteenth sheet and actuate an additional printing roller to print the paddle outline. These sheets could then be conveyed to an automatic nailing machine, stacked, nailed, and ejected to a product designed conveyor for transportation to either an automatic or manual sawing operation.

The cutting operation consists of guiding the workpiece through a cutting instrument in accordance with control information. As has been stated, a controlled saw table could move the workpiece into the saw, as would a photoelectric line follower.

The operator function in the sanding operation is one of positioning the paddle to rotary sander. The sander could effectively be positioned to all edges of the paddle by building two sanders, each of which would have sanding surfaces in a negative half contour of the paddle. Two of these units, operating much like a centerless grinder could receive paddles and simultaneously smooth all surfaces and then eject the units.

Regarding the assembly of balls to the rubber strands, there exists the possibility of evolving a mechanical device to perform the current operator functions of positioning the strand to the needle, the ball to the needle, and removal of assembled units from the needle. Due to the complexity of these operations, a completely mechanical device may be unfeasible. In a semi-automatic operation, using the current needle piercing method, the operator could position the strand to the needle, and an automatic ball feed could position the ball to the needle point; a hydraulic or air piston could drive the ball on to the needle and a like mechanism could remove the assembly. Thus one operator could tend several machines, only performing the function of threading the rubber strand to the needle which would otherwise require a complex mechanical operation. Balls could drop release to a feed conveyor leading to the paddle-ball assembly station. Due to the nature of the rubber strands, it may be difficult to use automatic positioning equipment for this final assembly.

The principles which have direct applications in Plant Nine are:

Processing of Continuous Form Material
Artificial Continuous Processing
Mechanical Feeding Equipment
Live Storage of Material
Intermachine Transfer
Analysis of Operator Functions

Computed operating ratios for Plant Nine are:

Production Value : Equipment Investment 8.33

Payroll : Equipment Investment	1.33
Equipment Investment : No. Production Personnel	$ 1,364
Production Value : No. Production Personnel	$11,364

PLANT TEN

Instead of the product and process considerations presented in the previous plant surveys, four operations involving operator functions have been observed and analyzed for the purpose of determining the exact nature of operator functions. These observations are presented in chart form in Tables 2, 3, 4, and 5, and are discussed separately below.

PRESS OPERATION

Table 2 presents the observations of a press operation. The work to be performed is that of crimping two edges of a stove pan; the operator obtains the workpiece from a pallet, positions it to the machine, and actuates the press. After one crimping operation the operator removes the workpiece and positions the opposite end to the press dies to crimp again; the unit is then placed aside on another pallet.

It is observed from Table 2, that the operator is performing mechanical actions in transporting materials, and performing a control function by actuating the machine. The machine is completely passive until actuated at which time it cycles.

What is obviously necessary is a means of transporting and positioning material to the press, and machine actuation. Incoming materials are presently received on pallets; a feeding mechanism for materials in this form would be unnecessarily complex, consequently it is indicated that the units should be fed, perhaps on guide rails from the preceding operation

Table 2

Man-Machine Functions of a Press Operation

MAN-MACHINE FUNCTIONS ANALYSIS CHART

PROCESS Crimp edges of stamped stove pan NO. OPRS. 1 NO. MACH. UNITS 1

FUNCTION OF PROCESS Crimp two edges PRODUCT Stove pan DATE March 15, 1955

NO. EQUIP. TYPES 1 Press

ANALYST Hohenstein

OBSERVATIONS: ☐ DIRECT ; ☒ FILM SHEET ____ OF ____

METHOD: ☒ PRESENT ☐ PROPOSED

◁ SIGHT O HEARING ⇒ TOUCH Y TASTE/SMELL ★ CREATIVE THOUGHT

O OPERATIONS ⇨ TRANSPORTATIONS ☐ INSPECTIONS

OPERATION		MAN							MACHINE	
DESCRIPTION	SYM.	PHYSICAL ACT	MENTAL PROCESS	Y	O	⇒	◁	★	PROCESS FUNCTION	AUTOMATIC ACT
Get material and position	➡	Get from pallet					x		Wait	
Position to machine	O	Position	Observe relative position				x		Wait	
Actuate machine	O	Foot actuate				x			Operate	No automatic actions
Remove material from machine	O	Unload					x		Wait	
Reposition material	O	Position	Observe relative position				x		Wait	
Actuate machine	O	Foot actuate				x			Operate	
Remove material from machine and ~~load to pallet~~	➡	Transport					x		Wait	

directly to this one. Two or more microswitches connected in series mounted on or adjacent to the die could serve as means of detecting correct workpiece position and consequently actuate the machine. A means of automatic ejection is then necessary; various mechanical ejector pins could serve as an ejector as could a blast of air.

It is noted that the operator can perform either of these functions (control or mechanical) with automatic actions for the other. Consequently if the automatic feed and ejection devices were considered infeasible, it may be possible to retain the manual feeding but with automatic microswitch or photoelectric machine actuation. In conjunction with such an automatic actuating device, a positive operator safety device would be desirable.

GRINDING CAST LAWN SEAT BACKS

The objective of this operation is to remove rough areas from cast lawn seat backs. This is accomplished manually with a grinding wheel to which an operator positions and grinds the workpieces. The operator must inspect each unit for defects prior to machining and then continuously control the position of the workpiece in relation to the grinding wheel. The operator functions of this operation differ from the previous one primarily in that the positioning and control functions are inter-related; the position of the workpiece is controlled by observations of the area to be ground (which has been termed a feedback observation). The process variables appear to be the location of the grinding area and the amount of material to be removed. If these variables can be isolated and determined quantitatively, then a basis may be developed for the automatic grinding of the seat backs.

Table 3

Man-Machine Functions of a Grinding Operation

MAN-MACHINE FUNCTIONS ANALYSIS CHART

HOHENSTEIN

PROCESS Cast lawn seat fabrication NO. OPRS. 1 NO. MACH. UNITS 1

FUNCTION OF PROCESS Remove burrs from casting PRODUCT Seat back DATE March 15, 1955

NO. EQUIP. TYPES 1 Grinder

ANALYST Hohenstein

OBSERVATIONS: ☐ DIRECT ; ☒ FILM SHEET ____ OF ____

METHOD: ☒ PRESENT ☐ PROPOSED

∢ SIGHT; O HEARING; ⇒ TOUCH; ♀ TASTE/SMELL; ○ OPERATIONS; ⇨ TRANSPORTATIONS; ☐ INSPECTIONS; ★ CREATIVE THOUGHT

OPERATION		MAN							MACHINE	
DESCRIPTION	SYM.	PHYSICAL ACT.	MENTAL PROC'S	♀	O	⇒	∢	★	PROCESS FUNCTION	AUTOMATIC ACT.
Get material	→	Transport					x		Wait	
Inspect	☐	Check casting for imperfections	Decision				x		Wait Machine runs continuously	No automatic actions
Position to grinder	○	Position	Observe relative position				x		Wait	
Grinds	⊖	Positions workpiece against grinder. Moves piece as burrs are ground off.	Feedback observation. Moves unit as result of rate of grinding. Decision.				x		Grinds	
Aside	→	Transport. Drops to container.	Observation of completed grinding.				x		Wait	

This operation illustrated the flexibility of human operators; if the variables mentioned above cannot be isolated, it would be difficult to construct an automatic machine to duplicate the manual functions; if they can be isolated, and a machine is constructed to grind the seat backs, the appearance of a rough spot at an area which is not at the predetermined grinding area will, of course, not be ground since it is outside the design characteristics of the machine. The remaining alternative to the automation of this operation is a consideration of revising the overall process.

This operation is of interest because it demonstrates interrelated control and handling functions, and flexibility of human performance which is difficult to duplicate.

SPOT WELDING OF SHEET METAL LAWN SEATS

This operation is similar to the first discussed since the operator functions are those of transporting the seat to the area of the spot-welder, positioning to the welder, and actuation of the machine. In addition, the operator must clamp and unclamp the angle iron to the stamped seat. Again, if machine utilization is a major factor, it would be worthwhile to investigate the possibility of providing an additional operator to clamp the two units, transport the assembly to the positioning operator and unclamp the completed units. Also the use of two spot welders would allow the operation to be completed in one positioning action instead of two. If two such units were used, it is conceivable that a positioning mechanism would allow the part to slide under the welding heads, with machine actuation by microswitches or photoelectric beam interruption.

Table 4

Man-Machine Functions of a Spot Welding Operation

MAN-MACHINE FUNCTIONS ANALYSIS CHART

PROCESS Lawn seat fabrication NO. OPRS. 1 NO. MACH. UNITS 1

FUNCTION OF PROCESS Spot-weld angle iron support PRODUCT Stamped lawn seat DATE March 15, 1955

NO. EQUIP. TYPES 1

ANALYST Hohenstein

OBSERVATIONS: ☐ DIRECT ; ☒ FILM SHEET ____ OF ____

METHOD: ☒ PRESENT ☐ PROPOSED

∢ SIGHT, O HEARING, ⇒ TOUCH, Ɣ TASTE/SMELL, ★ CREATIVE THOUGHT

O OPERATIONS, ⇨ TRANSPORTATIONS, ☐ INSPECTIONS

OPERATION DESCRIPTION	SYM.	MAN: PHYSICAL ACT.	MAN: MENTAL PROC'S	Ɣ	O	⇒	∢	★	MACHINE: PROCESS FUNCTION	MACHINE: AUTOMATIC ACT.
Get seat	→	Transport fm pallet	Observes location and posit to workplace				x		Wait	No automatic actions
Positions angle iron to seat	O	Obtain and position	Observes posit.				x		Wait	
Clamps angle iron to seat	O	Actuates clamp	Observes posit.				x		Wait	
Positions assembly to machine	O	Handles and positions	Observes posit.				x		Wait	
Actuates machine	O	Foot actuate	Checks position			x	x		Weld	
Indexes seat	→ O	Transportation	Observes position				x		Wait	
Actuates machine	O	Foot actuate	Checks position			x	x		Weld	
Remove clamps	O	Disassembles clamps					x		Wait	
Aside workpiece	→	Transportation	Observes pallet position				x		Wait	

Ejection may be accomplished by a hydraulic table tilting action.

If the angle iron support is not to be manually attached, it would be necessary to provide a separate positioning unit for them with a control interlock to prevent machine actuation until all components were positioned.

The more basic observation is that the operator functions are divisible into control and positioning functions; it may not be desirable to automatize both functions, but rather to consider the automation of perhaps the control function separately retaining the operator for handling, where such action will contribute to more productive work.

POURING GRAY IRON

The operator functions of the pouring of gray iron as presented in Table 5 are primarily those of transportation and positioning the ladle. To automate these operations directly could well evolve into a complex and infeasible mechanical assembly. The overall function of the operation is to fill the molds, in one remote location, with molten gray iron, initially in another location. The operation variable is that of location of the molds; the operator transports ladles of molton iron to the various mold locations from one iron source. This movement is one of relative motion of the molten iron and the molds; i.e., the molds can be moved to the source, or the source can be moved to the molds. This latter alternative is, in effect, that which is accomplished now.

Control functions are primarily those of positioning the ladle to the filling spout and positioning the stream of molten iron to the mouth of the mold. Both of these functions can be automatized if sufficient

Table 5

Man-Machine Functions in a Foundry Operation

MAN-MACHINE FUNCTIONS ANALYSIS CHART

PROCESS Pouring gray iron in foundry NO. OPRS. 1 NO. MACH. UNITS (ladle) - 0

FUNCTION OF PROCESS Fill molds PRODUCT Various castings DATE March 15, 1955

NO. EQUIP. TYPES -

ANALYST Hohenstein

OBSERVATIONS: (first 3 elements direct) ☒ DIRECT; ☒ FILM SHEET ___ OF ___

METHOD: ☒ PRESENT ☐ PROPOSED

∢ SIGHT O HEARING ⇒ TOUCH ¥ TASTE/SMELL ★ CREATIVE THOUGHT

○ OPERATIONS ➪ TRANSPORTATIONS ☐ INSPECTIONS

OPERATION		MAN							MACHINE	
DESCRIPTION	SYM.	PHYSICAL ACT.	MENTAL PROCESS	¥	O	⇒	∢	★	PROCESS FUNCTION	AUTOMATIC ACT.
Position ladle to pouring spout	O	Position	Observe relative positions				x		Continuously pouring	
Remove when full	➔	Transport	Observe when full				x		Continuously pouring	
Move to monorail	➔	Transport					x		Mold waits to receive gray iron	
Position ladle to monorail	O	Position	Observe relative positions						"	
Move to mold area	➔	Transport					x		"	
Remove from monorail	O	Unload ladle from monorail					x		"	
Remove slag from ladle	O	Remove slag with rod.	Observe slag location				x		"	
Carry ladle to mold	➔	Transport	Observe location of mold				X		"	
Posit to mold	O	Position	Observe relative positions				x		"	
Pour	O	Tilt ladle	Observe correct position				x		Mold being filled	
Stop when full	O	Position ladle	Observe complete				x		Mold filled	
Return ladle	➔	Transport					x		Cools	

volume justifies the equipment necessary. Again, it may be advantageous to consider the automation of one of the above functions rather than both. An automatic materials handling installation which will deliver the molds to a central pouring area, perhaps with live conveyor storage of the molds, may be advantageous.

CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

This study has generally indicated that there is a potential to use automatic techniques in medium sized Georgia plants; the feasibility of such installations is largely undetermined because no economic evaluations have been made. The inclusion of such an economic analysis in a future study is recommended. The plant surveys are believed to have indicated that no overall analysis of the processes have been made from the standpoint of automation. Inasmuch as a general potentiality is indicated, a future study of one process, including recommendations for specific units of equipment and an economic evaluation would be of value.

A basic relationship between methods analysis and considerations for automation has been observed. Since automation or automatic techniques is one alternative of the possible methods of production, automation is consequently within the scope of methods analysis. Methods analysts should therefore reinforce themselves with a knowledge of automatic techniques and thus be prepared to detect and evaluate automation installations.

As an aid to these methods considerations, 15 proposed principles have been generalized from observed patterns of current automatic activities. An attempt has been made to apply these proposed principles to the observations of existing processes. The exercise of these principles indicates that they are of value in such automatic system development. The developed principle concerning processing material in continuous form rather than in discrete units has been found to be the most universally applicable and has suggested process modifications of a wide scope.

The discussions with management members have shown that management interest and knowledge has ranged from total unfamiliarity to aggressive evaluation. Generally, management has stated that their current process could not use the developments in automaticity at present. Automation was felt to be applicable to only larger organizations with continuous runs which could afford large equipment investments. While almost half of the firms stated that process evaluations had been made, observations of the processes and discussions with plant personnel indicated that such analyses were not comprehensive and all-inclusive. The impression was given that these evaluations were closely related to the developments of machinery manufacturers. Special machinery developments were not apparent in the majority of plants visited and only one management member reported that such machinery, on a large scale, was under development. There is, of course, no assurance that the other organizations are not doing so also.

Regarding the processes in general, it is unlikely that complete automaticity could be effectively utilized, however, it was observed that opportunities exist in all the plants visited for the automation of sections of the processes. In addition, many opportunities were noted for non-automatic methods improvements. Observations of operator functions have shown that they consist of transportation and control activities, though often inter-related. It appears feasible to use physical equipment to replace either, and not necessarily both the transportation and control functions.

Control of a process or operation has been found to be an information processing activity. As the control function increases in complexity, the equipment needed for automatic control also increases; human control has been evaluated as the most flexible means of control and consequently for complex control situations, combinations of human and automatic control should be balanced to achieve feasible control installations. The use of large scale computing equipment for conditional control and simulation is not considered feasible in the plants visited, though limited use of computer components may be warranted.

Table 6 summarizes the economic data obtained from the plants visited. It was intended to determine which, if any of these ratios indicate the relative states of automation of the processes. The first ratio, that of Annual Value of Production : Production Equipment Investment is lower for the plants with more automatic equipment. Plant Four, however, has a lower ratio than Plant One and is considered less automatic; if these relative states of automaticity exist as stated, then it is concluded that either the data obtained is not accurate or that this ratio is not a good indication of the relative states of automaticity. The ratio of Annual Production Labor Payroll : Production Equipment Investment shows a higher value for the less automatic plants. The third ratio which is Production Equipment Investment : Number of Production Personnel has a lower value for the less automatic plants. This ratio, it has been found, is similar to the previous one, differing from the inverse of the second ratio as a function of the annual wages of the employees. The fourth ratio computed, that of Production Value : Number of Production Personnel indicates those plants which are relatively non-automatic have lower values.

The correlation of the economic ratios with the existing state of automaticity of the processes visited involves the intuitive ranking of

Table 6

Summary of Economic Ratios From the Plants Visited

Plant No.	Production Value / Equipment Investment	Annual Payroll / Equipment Investment	Equipment Investment / Number Personnel	Production Value / Number Personnel
1	6.51	0.36	$6,221	$40,502
2	7.93	1.12	$3,024	$23,967
3	- -	- -	- - -	- - - -
4	3.57	0.86	$3,500	$12,500
5	- -	6.00	$ 313	- - - -
6	10.00	0.90	$2,857	$28,571
7	10.00	1.95	$ 889	$ 8,889
8	- -	- -	- - -	- - - -
9	8.33	1.33	$1,364	$11,364
10	- -	- -	- - -	- - - -

the plants. All of the ratios roughly indicate those plants with little or no automatic equipment. Equipment investment is not a stable figure which can be compared from plant to plant. Production value is even less stable; the annual wholesale value of production was requested, but this value was stated by one executive to vary between periods of time for a constant volume of production. Also wholesale value can change while the product is in inventory. The annual wages of employees have been found to vary, with the larger salaries being paid to employees of the more automatic plants. Consequently, the ratio of Equipment Investment : Number of Production Personnel, even though it uses the questionable value of Equipment Investment is favored over the other ratios as an indication of the relative state of process automaticity. Plants with values for this ratio below $1,000 have been found to embody a large amount of manual operations; between $1,000 and $4,000 the processes use primarily mechanical equipment and operator combinations. The one plant visited which had a value above $4,000 (Plant One; $6,221) was apparently the most automatic with relatively few operator functions though most variables were manually controlled. Care should be exercised that this ratio serves only to indicate relative states of the automaticity of processes and not the most efficient process. Production objectives are, of course, to maximize profits and not to maximize the ratio of Equipment Investment : Number of Production Personnel.

Several other specific conclusions are:

1. The use of the term "automation" may serve to unduly influence process design to detracting from the optimum method in order to achieve a titled process.

2. The major benefit of manual control is versatility, while the main advantages of automatic control are the release of oper-

ators from repetitive control tasks and an inherent speed of reaction.

3. Repetitive control patterns can be stored in memory media and selected in accordance with a conditional action.
4. Materials handling would be facilitated by flexible, multiple flow paths.
5. A combination of static storage containers and dynamic vehicles would facilitate automation of materials handling.
6. Automaticity of materials handling assumes two forms in the process phase: (a) the grouping of machines around a central materials handling unit, and (b) the use of special conveying, feeding, and unloading units.
7. Materials are handled with less difficulty while materials are in continuous form.
8. Automaticity of lot processes can be facilitated where those operations with characteristics of continuous manufacture can be segregated and continuously processed.

Regarding the steps to be taken in an analysis of a process for possible automation, the author suggests a functional analysis of the product for the determination of redesign possibilities which will permit automatic manufacture and the possible elimination of run differences. Next, the method of manufacture should also be functionally considered for possible basic change. Once the basic method of manufacture has been determined, it is recommended that consideration be given to the materials handling function by either compounding machines around a central materials handling unit (such as is done in transfer machines) or providing for automatic machine feeding and unloading. Simultaneously, consideration should be given to the variables which must be adjusted for run differences and the other variables which must be controlled. Automatic control equipment and operator control combinations should be balanced for feasible installations. And, of course, the economic feasibility of the overall installation must be determined.

Several potential thesis topics which have become apparent during the execution of this work are:

1. An Investigation of Real Time Applications of Digital or Analog Computers in Manufacturing Operations.

2. A Comprehensive Analysis of the Automation Potential of a Manufacturing Operation.

3. An Analysis of Operator-Controlled Variables in Several Industries.

4. A Synthesis of Automatic Control Techniques.

5. An Investigation of Automatic Materials Handling Techniques.

6. The Automation Potential of Several Fabricating Operations.

7. The Automation Potential of Several Flow Processes.

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